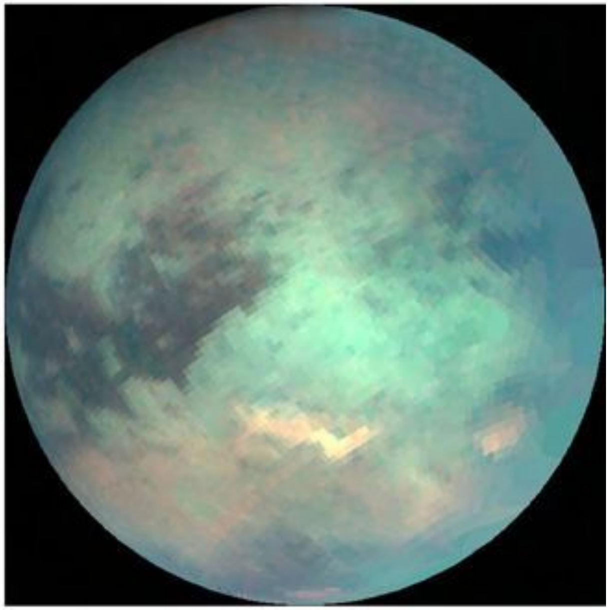
SCIENTIFIC RATIONALE OF FUTURE TITAN LANDING SITES

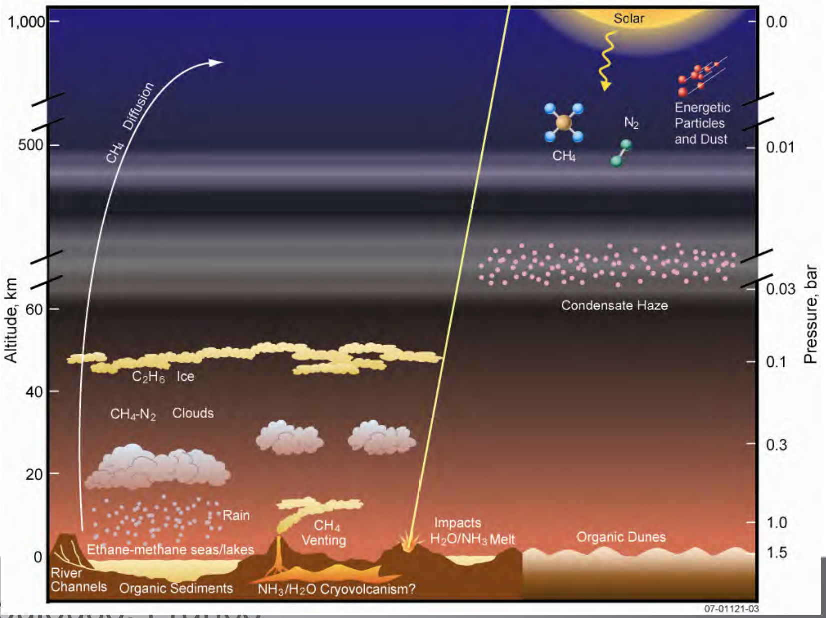
Ralf Jaumann*, Katrin Stephan, and Frank Sohl
Institute of Planetary Research, German Aerospace Center (DLR), Berlin
**e-mail: ralf.jaumann@dlr.de*
Anezina Solomonidou
National & Kapodistrian University of Athens
LESIA, Observatoire de Paris-Meudon
Athena Coustenis
LESIA, Observatoire de Paris-Meudon

Why Titan?

1. Similarity with Earth and the terrestrial planets in spite of ice-rich bulk composition
2. Titan is unique with regard to its organic inventory (atmosphere, lakes, surface, subsurface ocean interior)



understanding the processes that characterize Titan would provide an important link to comprehend the origin and evolution of life.

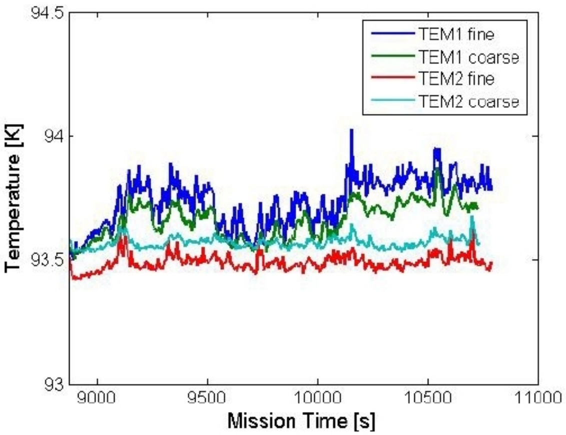


Surface Environmental Conditions

- Titan's near-surface environment:
  - low temperatures and high pressures
  - low diurnal temperature variations at the surface, wind speeds reach only 1 m/s,
  - large seasonal variations in temperature and pressure
  - fluvial processes driven by the methane cycle, leading also to the formation of methane-soaked regolith,

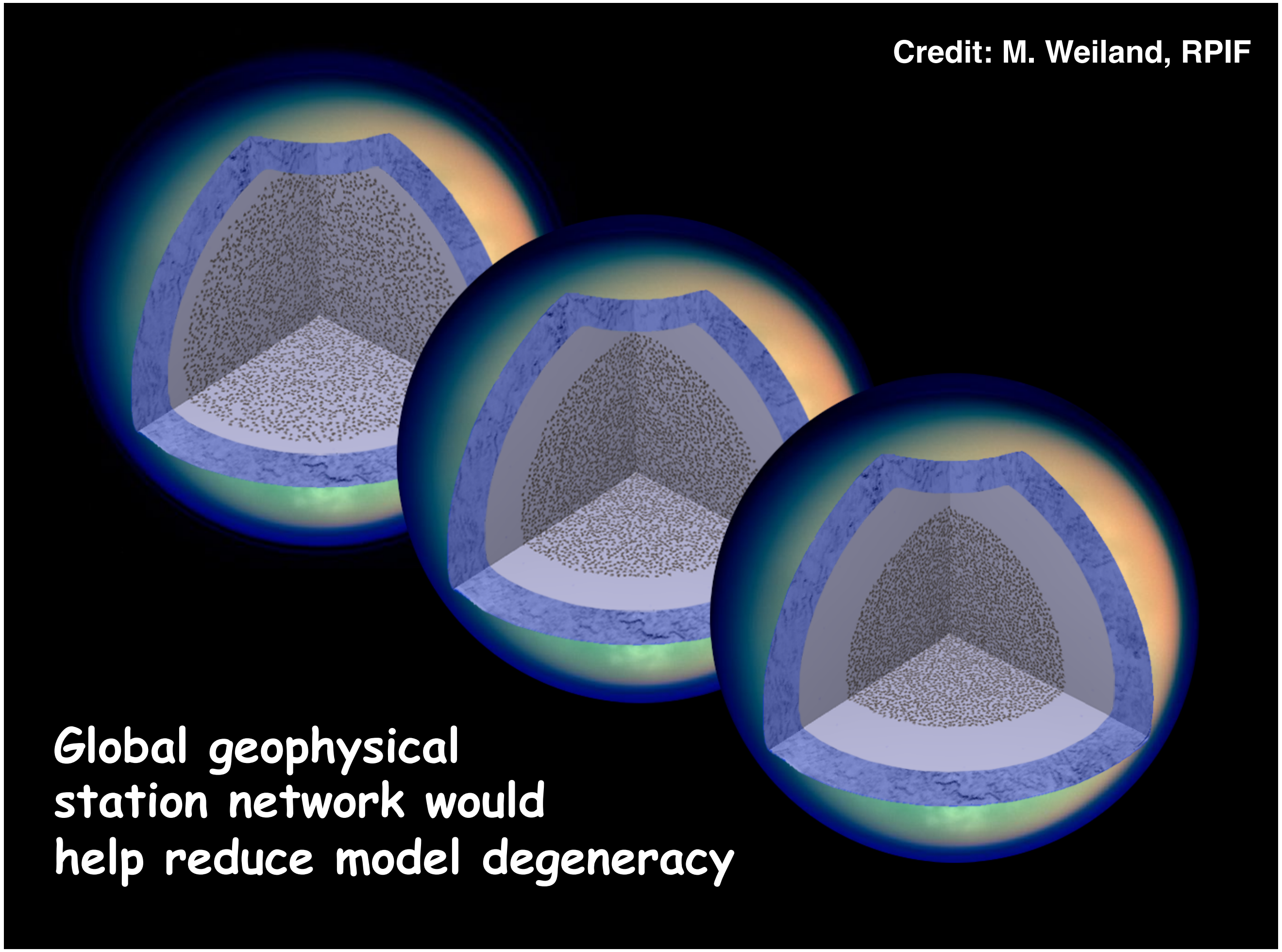
Meteo at surface:

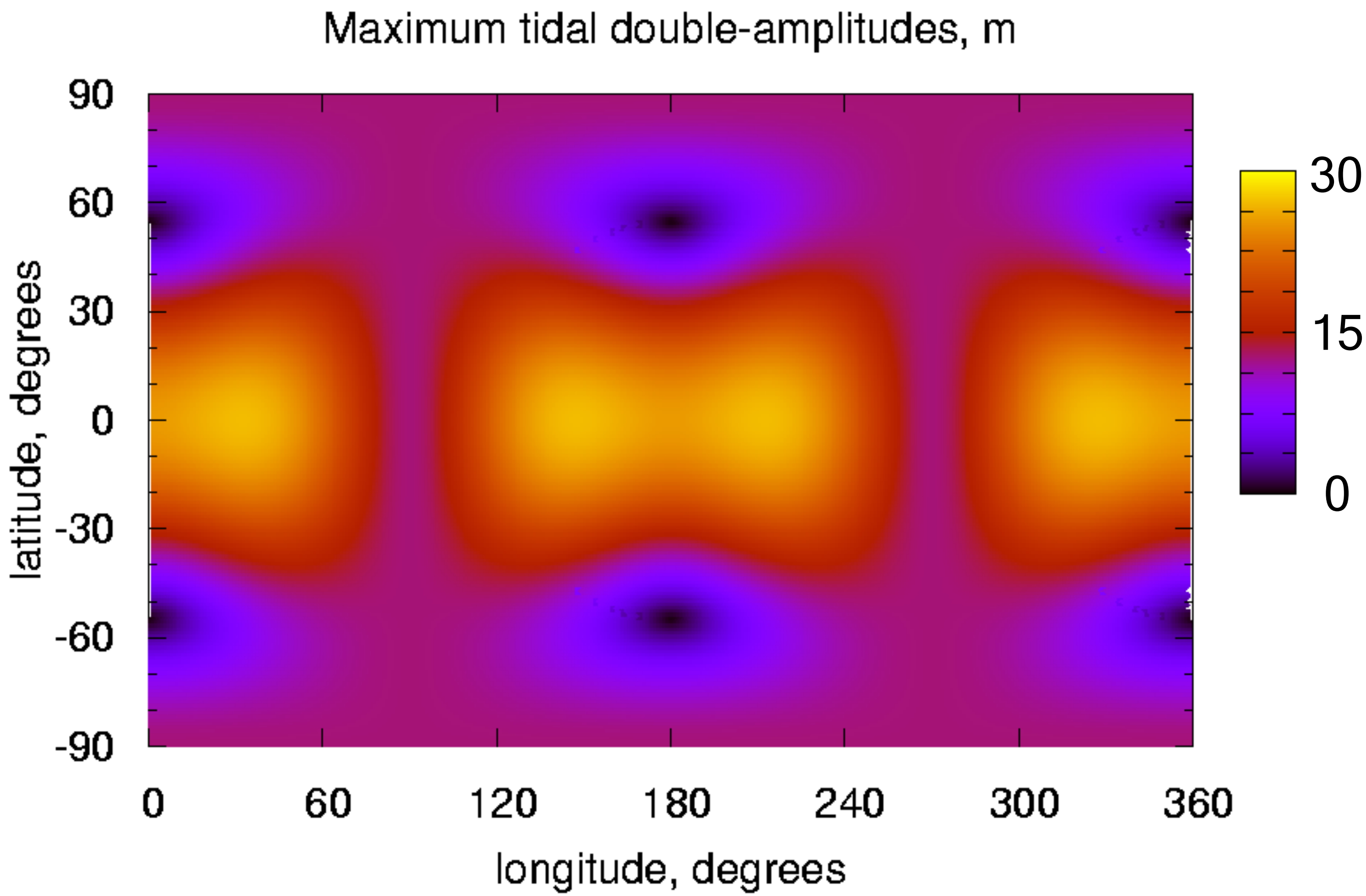
- **Temperature 93.65±0.25 K**
- **Pressure 1467±1 hPa**



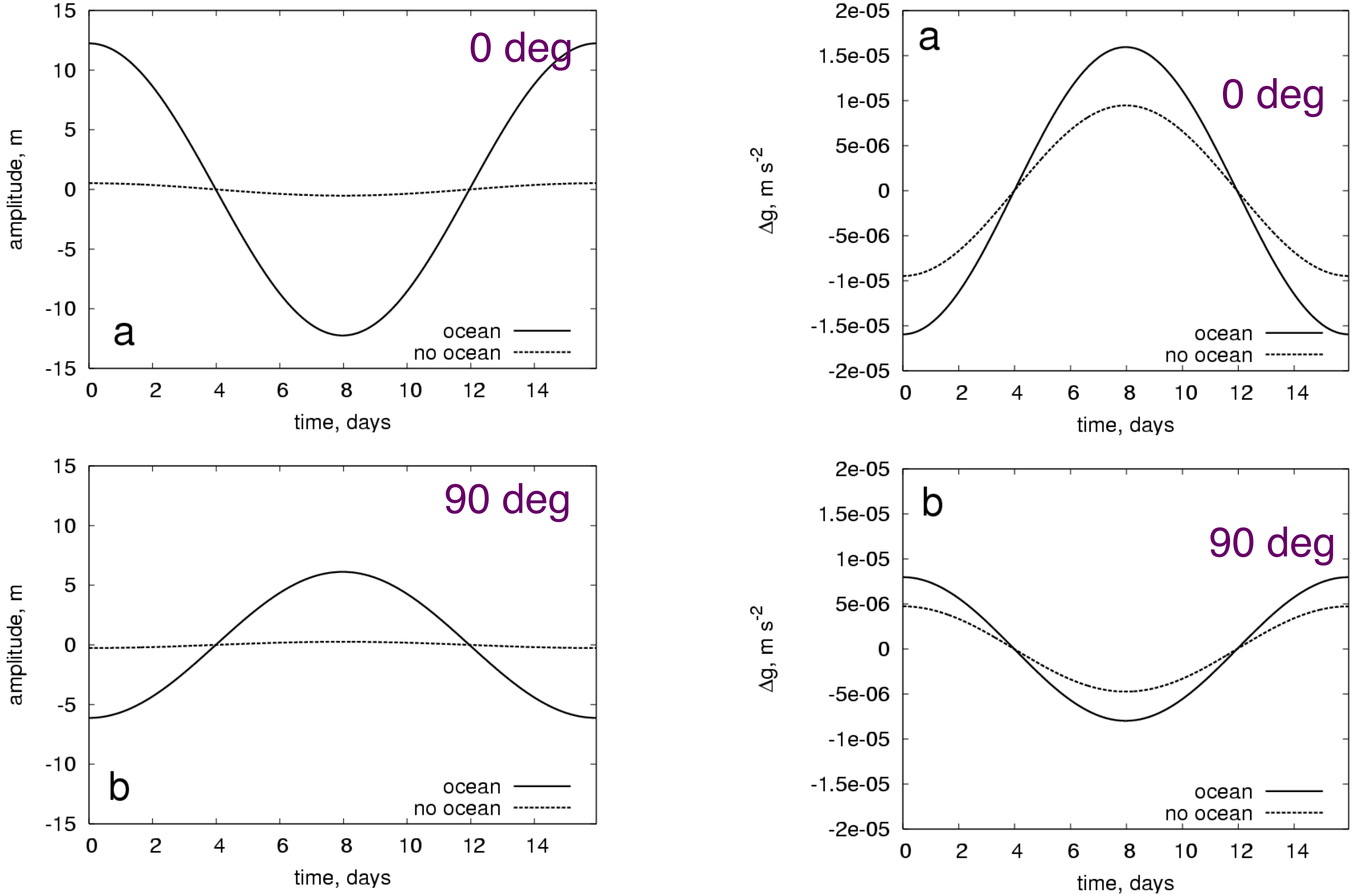
Structural Models of Titan

- Cassini gravity data suggest partial separation of rock and ice.
- Extent of separation of rock from ice would depend on rock density due to silicate hydration.
- Principal source of non-uniqueness.

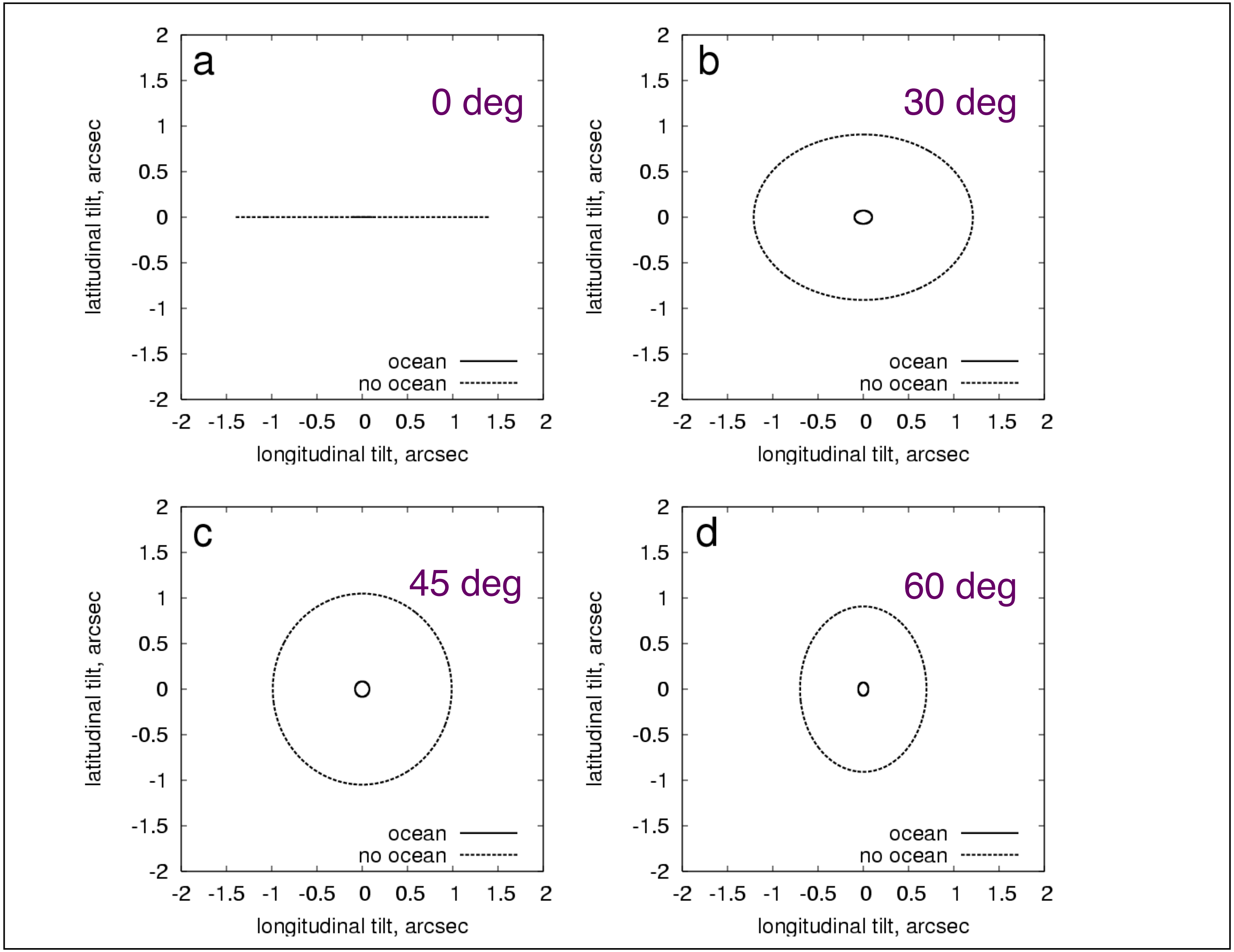



Maximum tidal double-amplitudes, m
90
60
30
0
-30
-60
-90
latitude, degrees
0
60
120
180
240
300
360
longitude, degrees
30
15
0

Tidal Displacement and Gravity



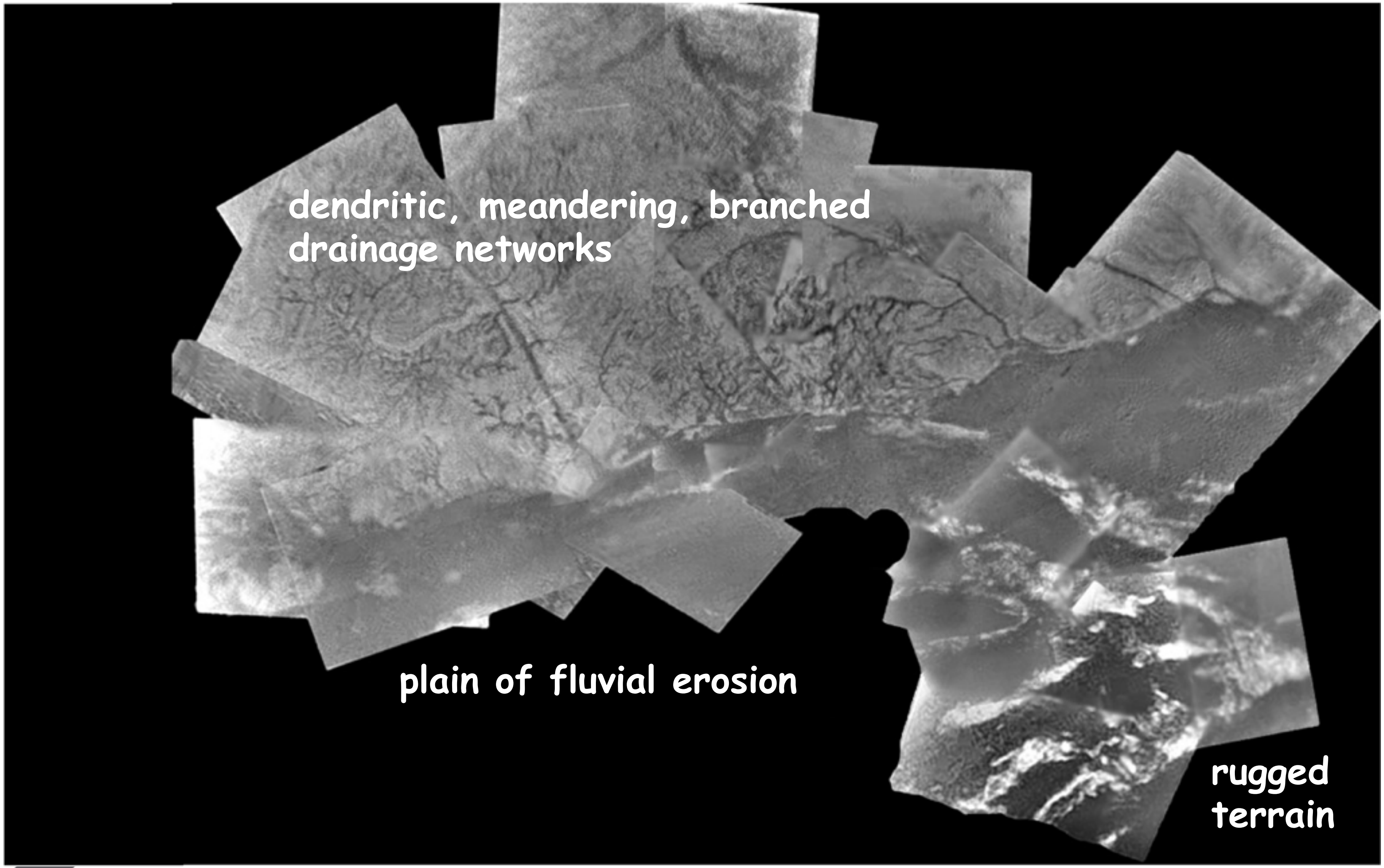
Tilt


a
0 deg
b
30 deg
c
45 deg
d
60 deg
ocean
no ocean
latitudinal tilt, arcsec
longitudinal tilt, arcsec

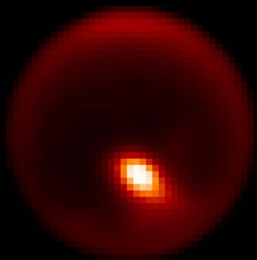
Take Home I

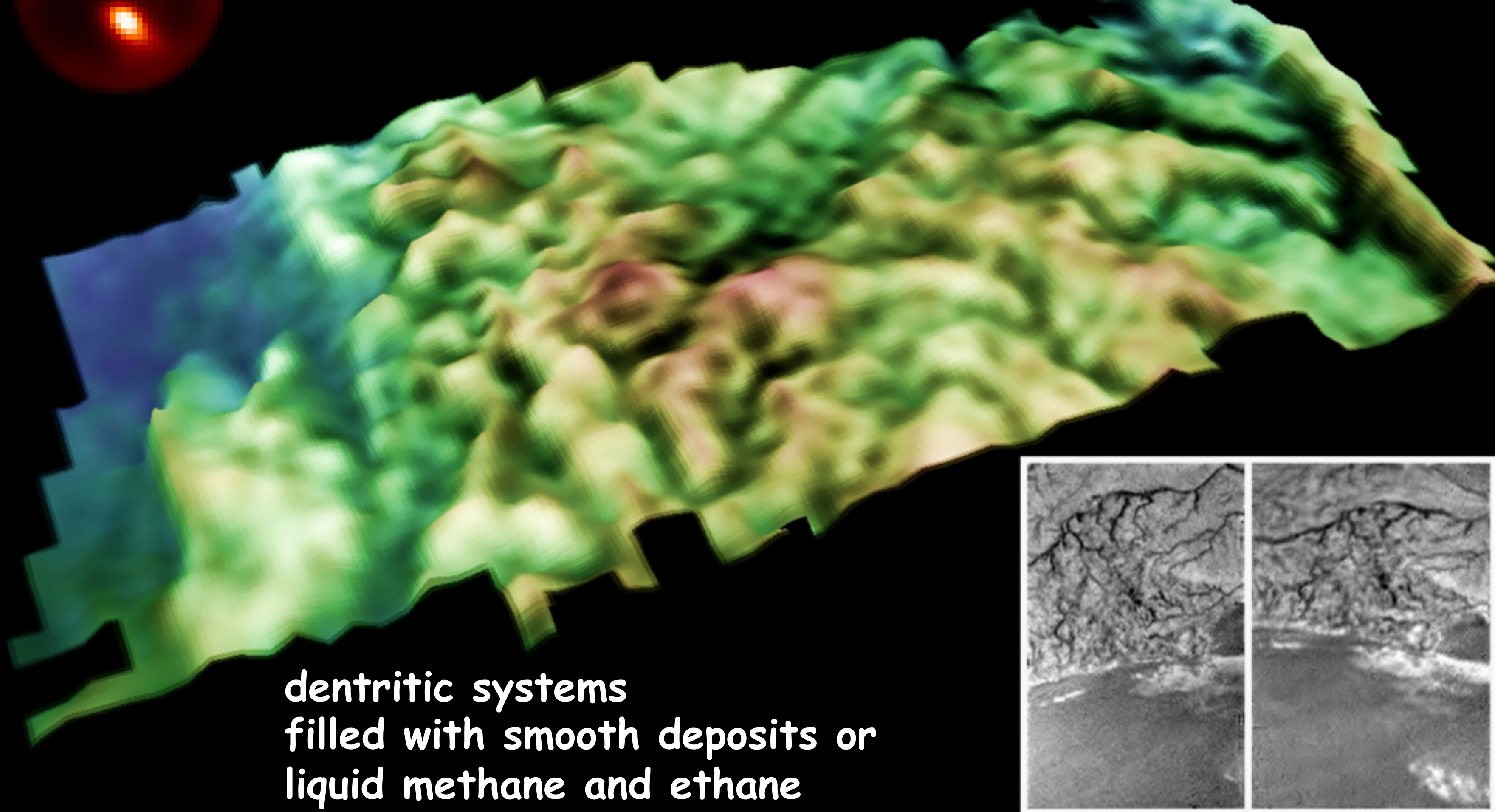
- **Titan's relationship to Ganymede and Callisto is still not clear**
- **Geophysical network science (stationary)**
- Global distribution, restricted to 2030+ illuminated hemisphere
- Mission duration 1 to 2 Titan days
- Cover pole, mid latitudes (45 deg, leading or trailing hemisphere), equatoral (sub- or anti-saturnian hemisphere)
- Local dispersion using several sub-lander
- **Science objectives**
- Tidal response and rotational state
- Seismic activity
- Time-variable magnetic field (induced and inducing)
- Near-surface properties of atmosphere, lakes, and regolith
- Environmental conditions

Erosional features around the Huygens Landing Site

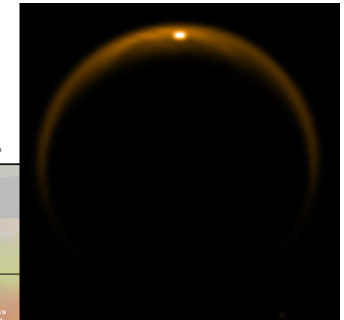


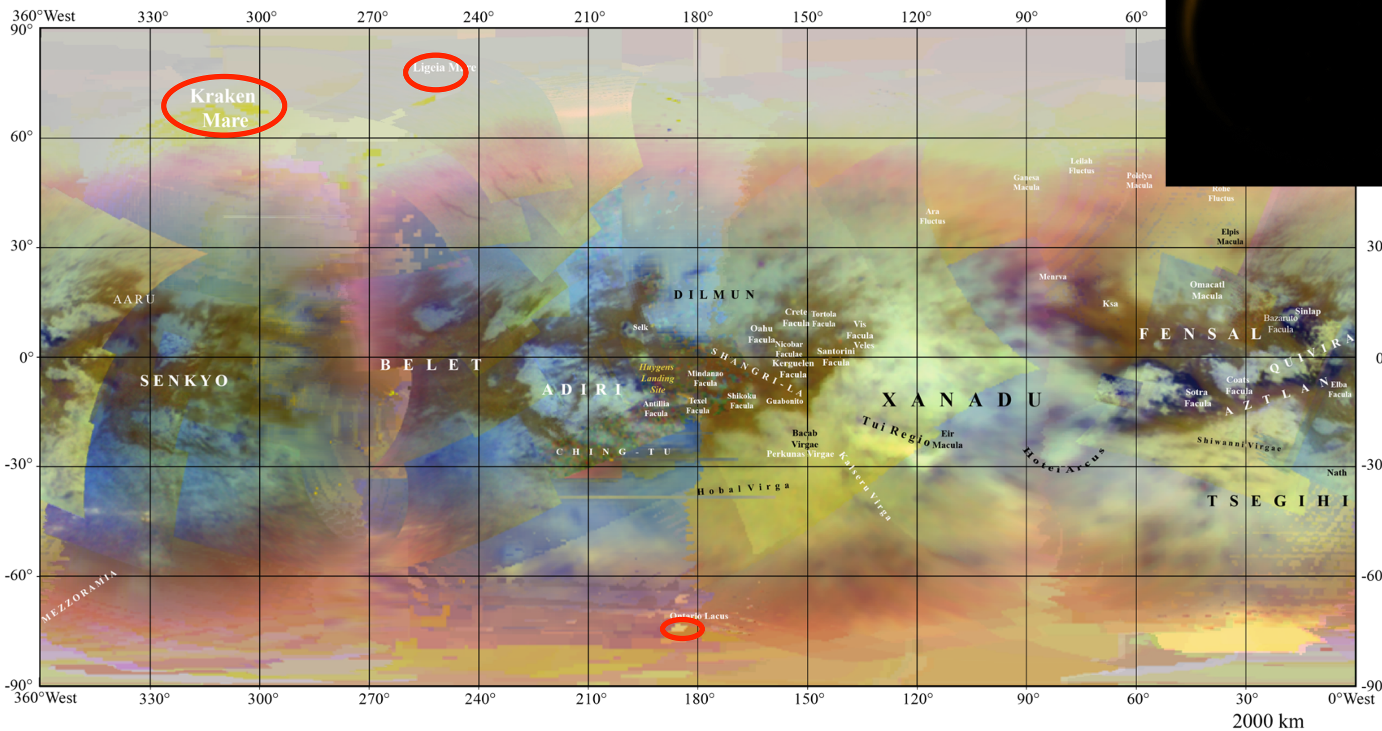
Erosional features on Titan





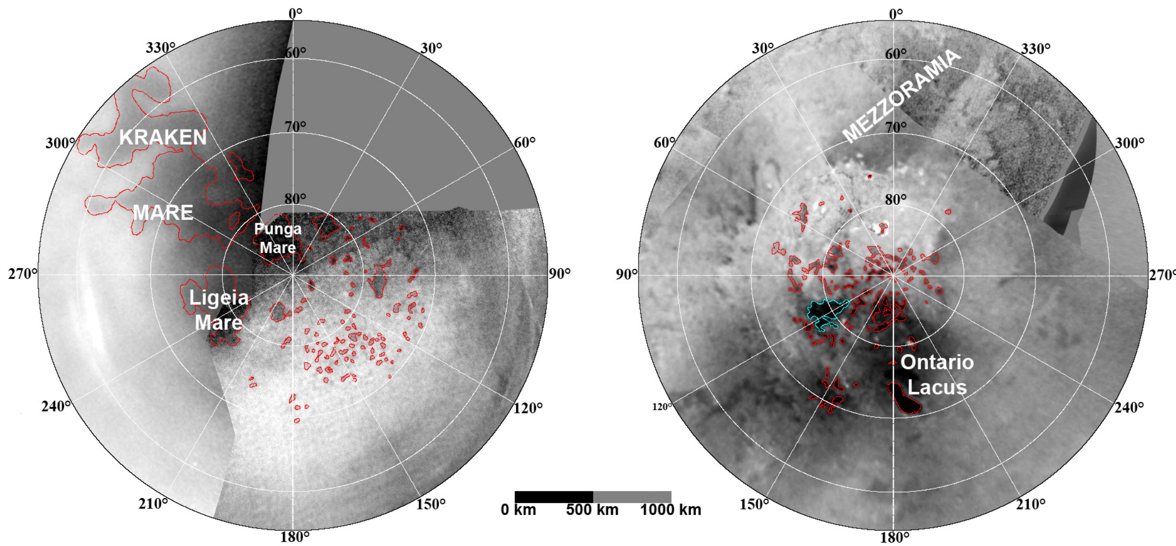
Polar Hydrocarbon Lakes





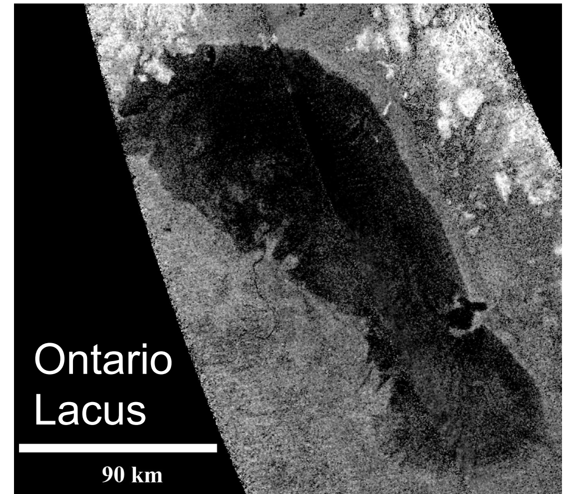
- Carbon cycle and production of organic solids
- Precipitation of aerosols from above, release of noble gases from below

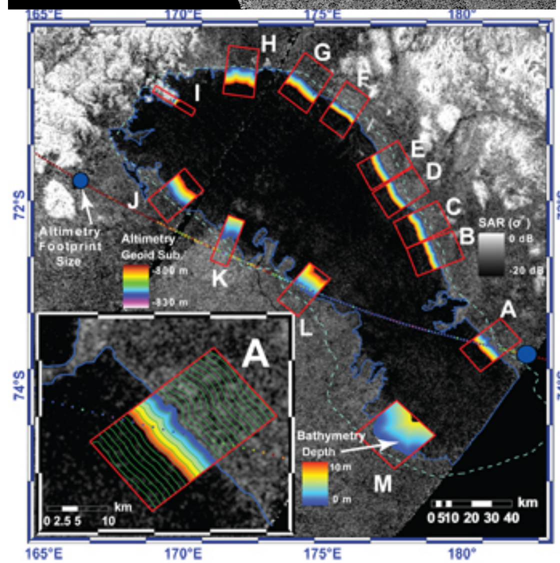
Polar Hydrocarbon Lakes



North Polar Region

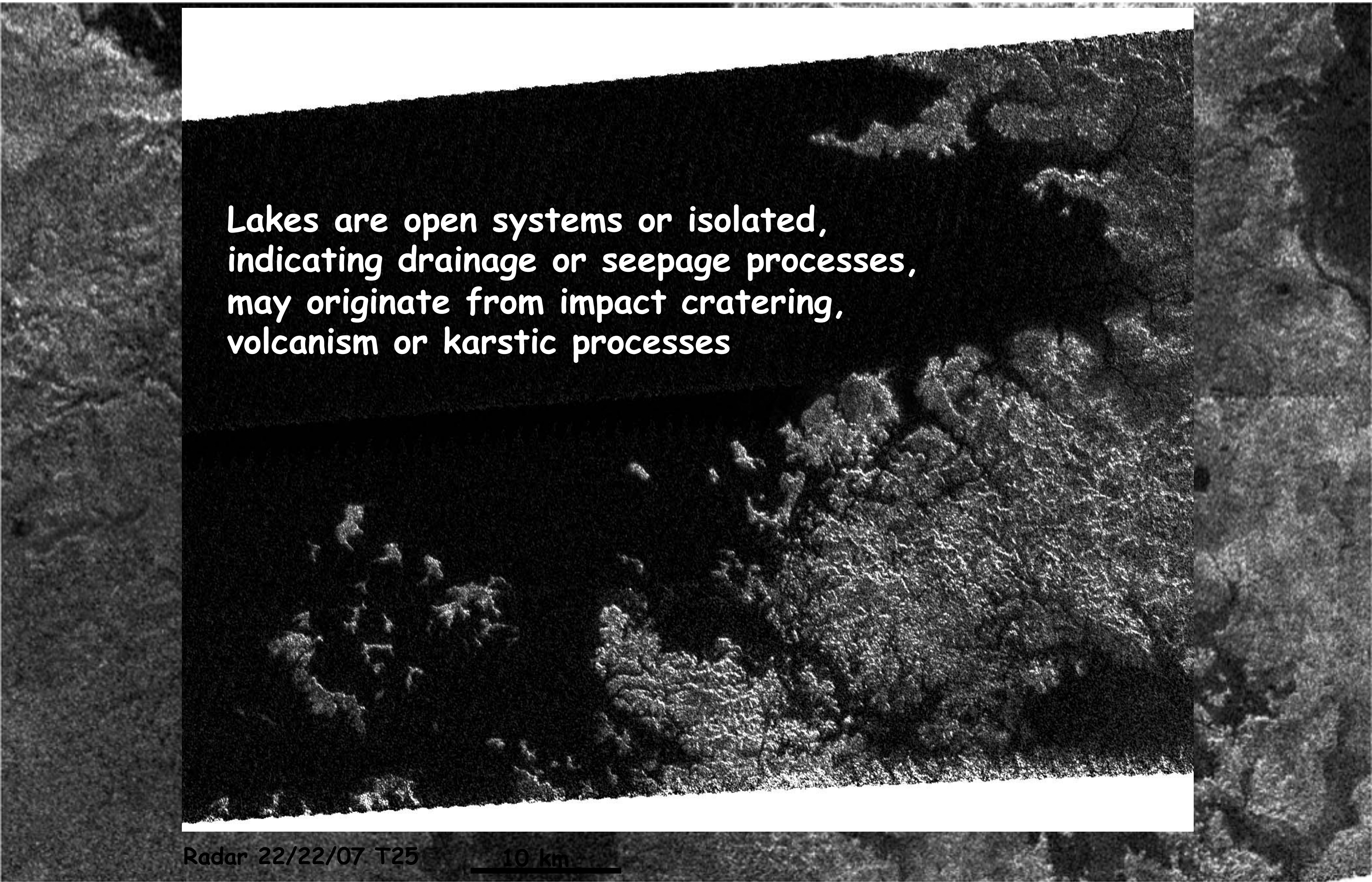
South Polar Region





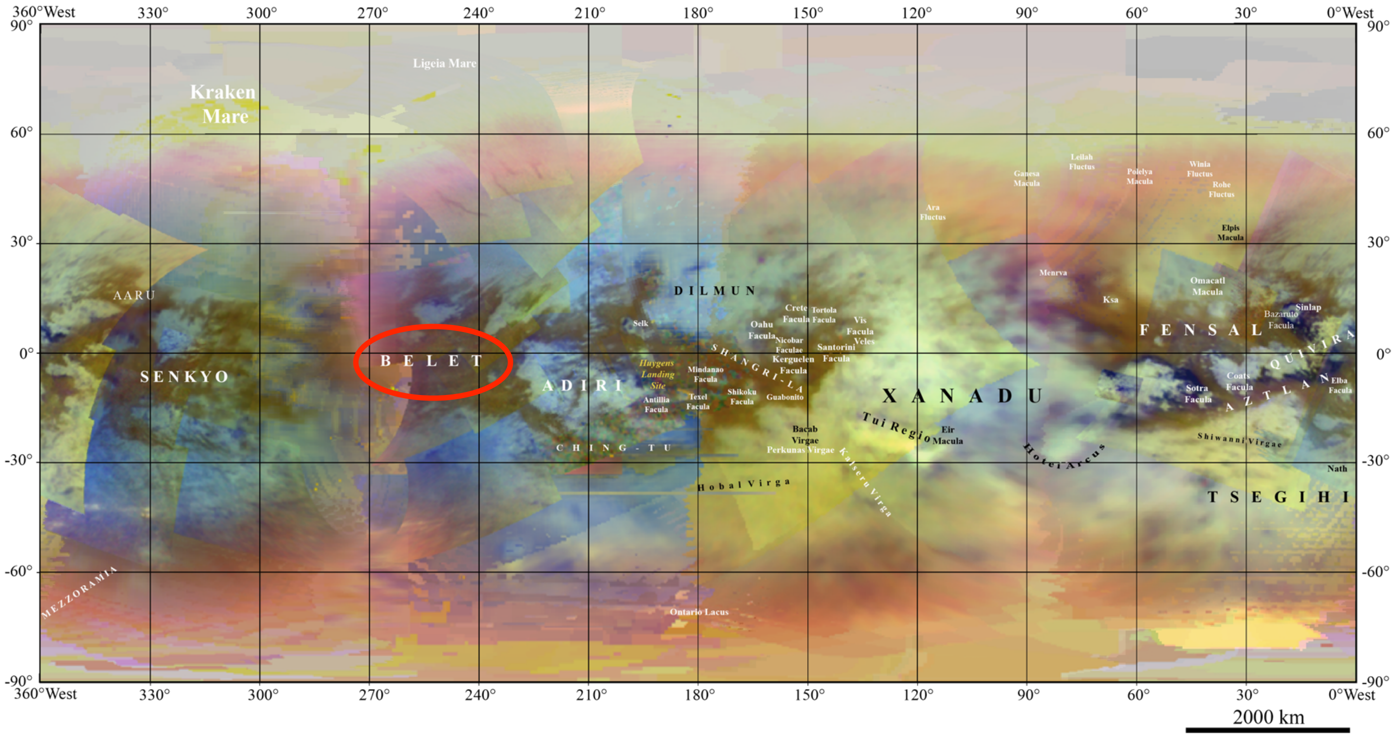
Credit: Radar Science Team, NASA/JPL/Caltech

- Lakes in northern high latitudes (> 70 deg) cover 20 times more area than lakes in the southern high latitudes.
- Shore lines primary targets for analysis of long-term climate and short-term seasonal changes
- Tidally-induced pressure variations in shallow lakes



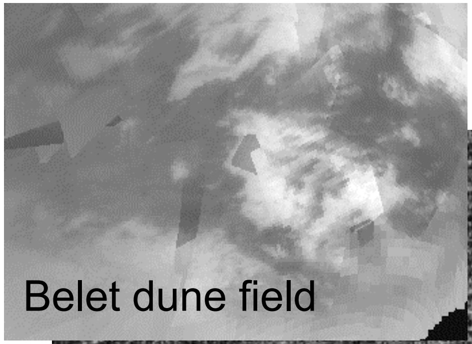
Lakes are open systems or isolated,
indicating drainage or seepage processes,
may originate from impact cratering,
volcanism or karstic processes
Radar 22/22/07 T25
10 km

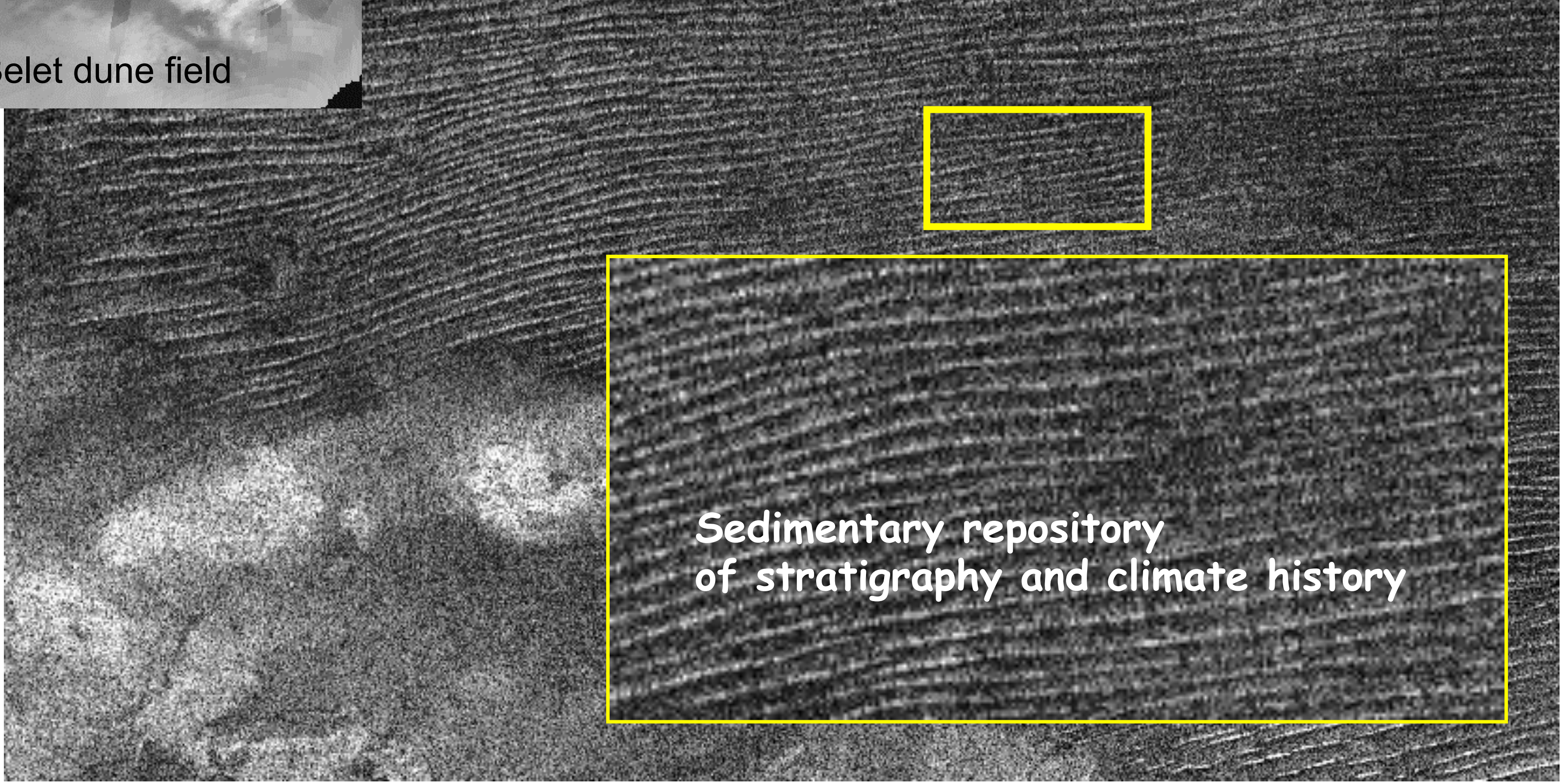
Equatorial Dune Fields



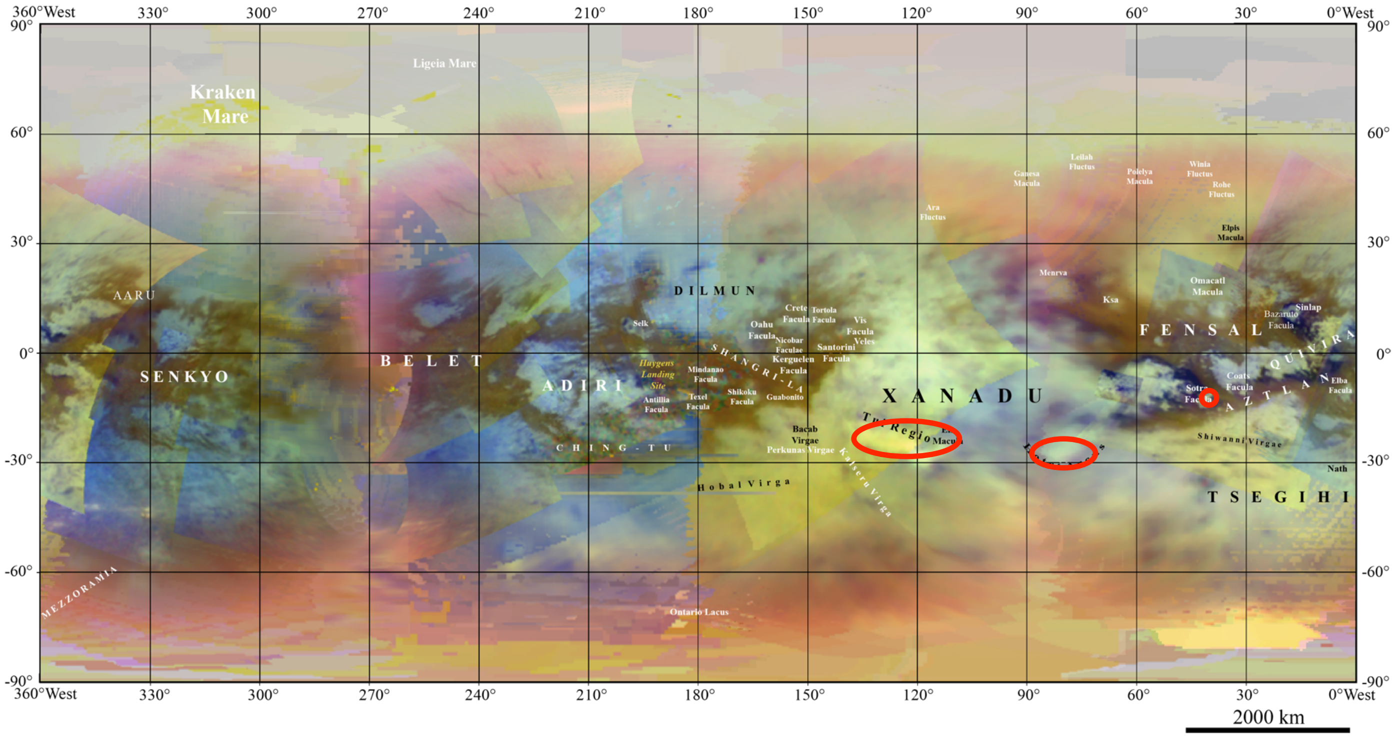
- Young aeolian surface features with high organic particle content
- Close relationship to recent erosional and depositional surface processes

Equatorial Dune Fields



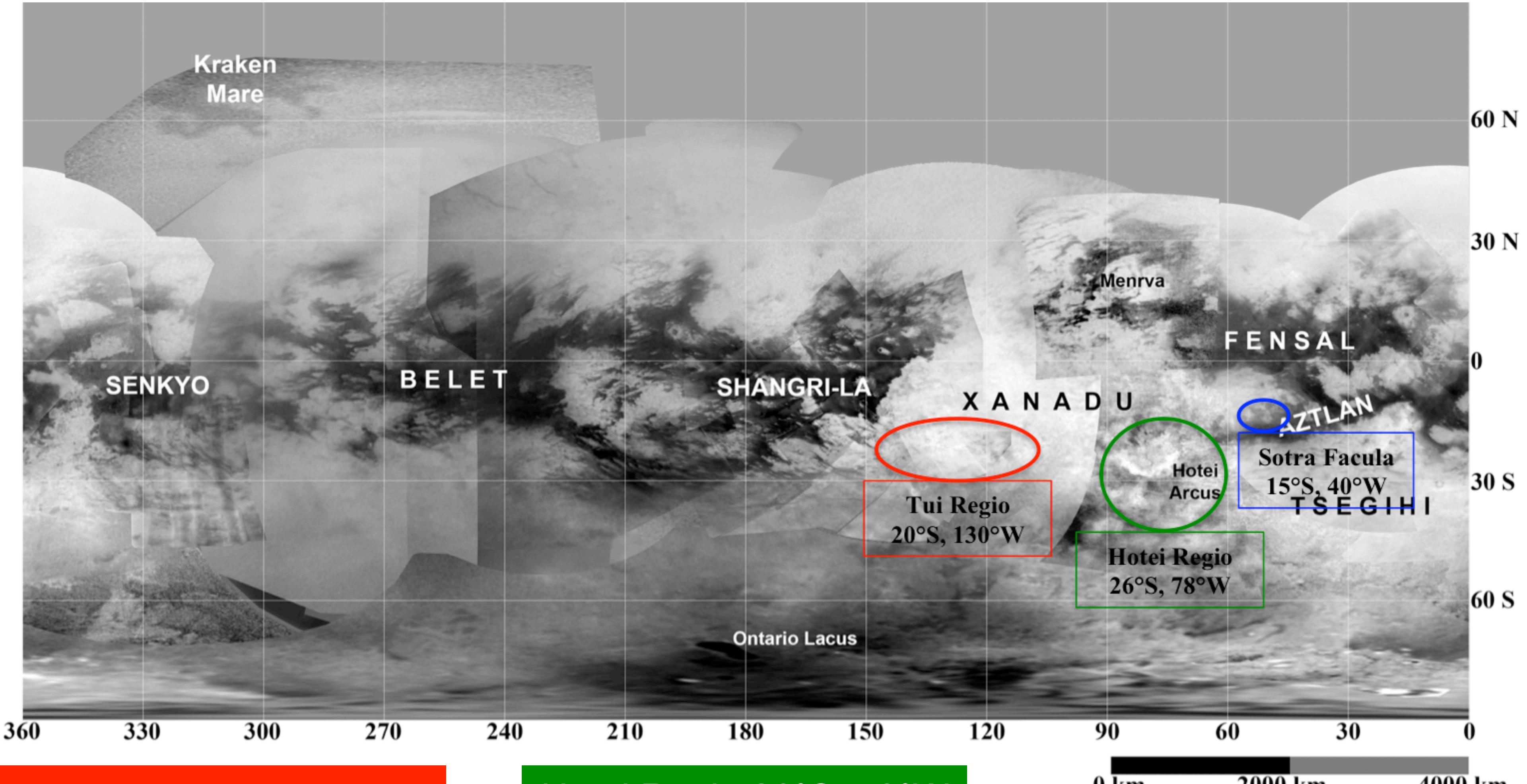


Cryovolcanic candidate areas



→ Combined information on atmosphere, surface, shallow subsurface and deep interior

Cryovolcanic candidate areas

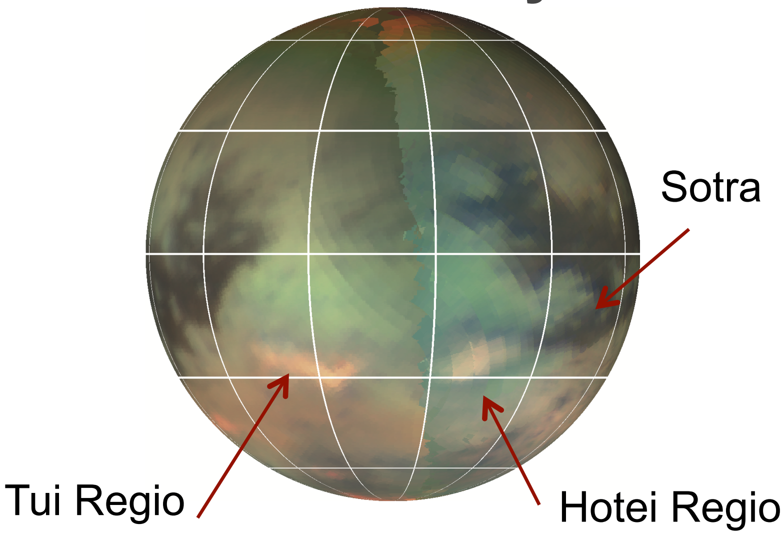


Tui Regio 20°S, 130°W

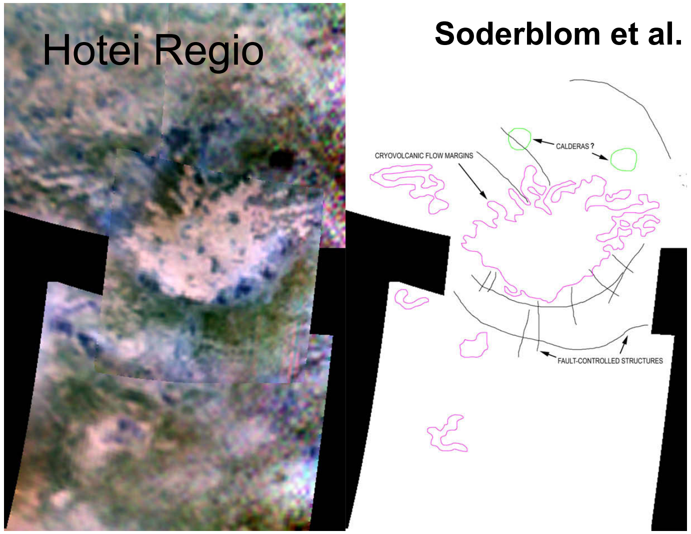
Hotei Regio 26°S, 78°W

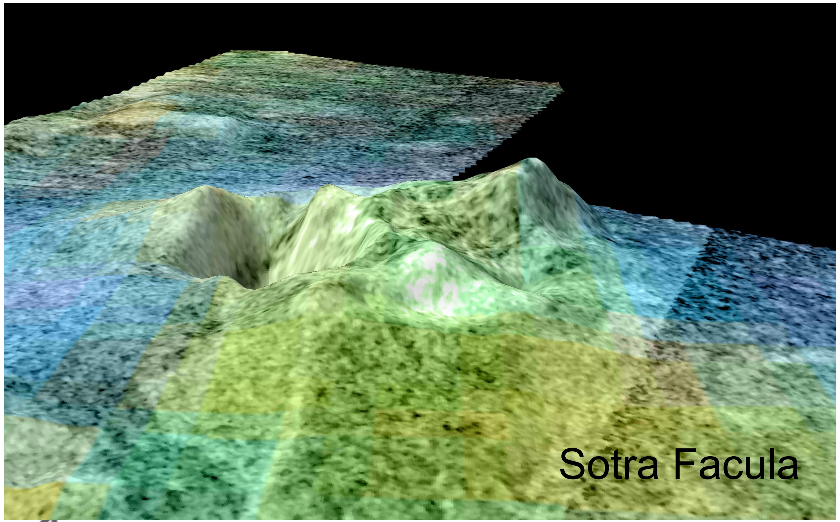
Sotra Facula 15°S, 40°W

Cryovolcanic candidate areas



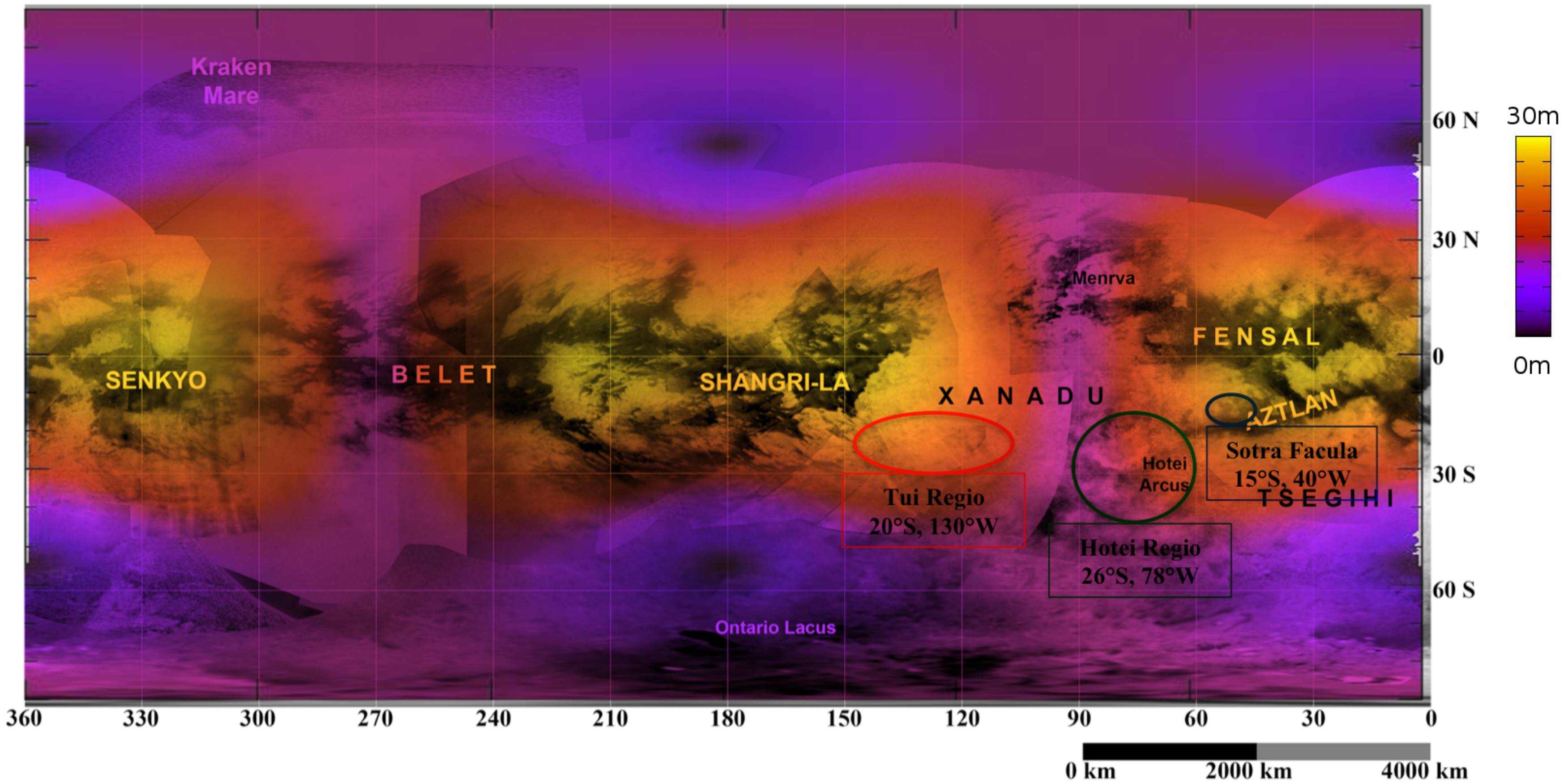
Soderblom et al. 2010





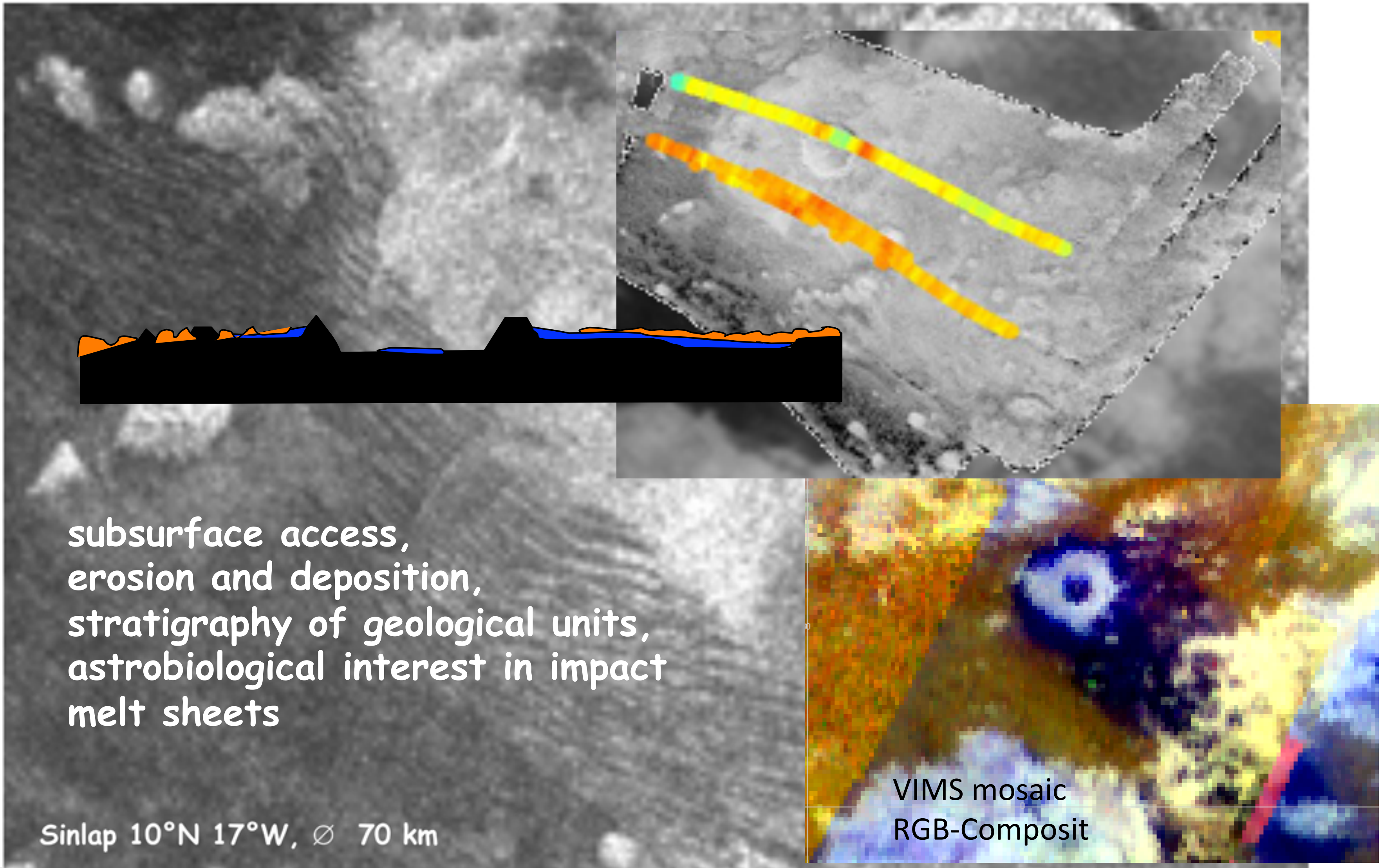
- Hotei: erosional crater formed by subrosion and deposition?
- Sotra: sequence of multiple cryovolcanic features surrounded by a series of bright lobate cryo-lava flows?

Tidal Amplitude Pattern Superimposed



- Some cryovolcanic candidate areas are situated in strongly tidally-flexed regions on Titan.

Impact Craters



Take Home II

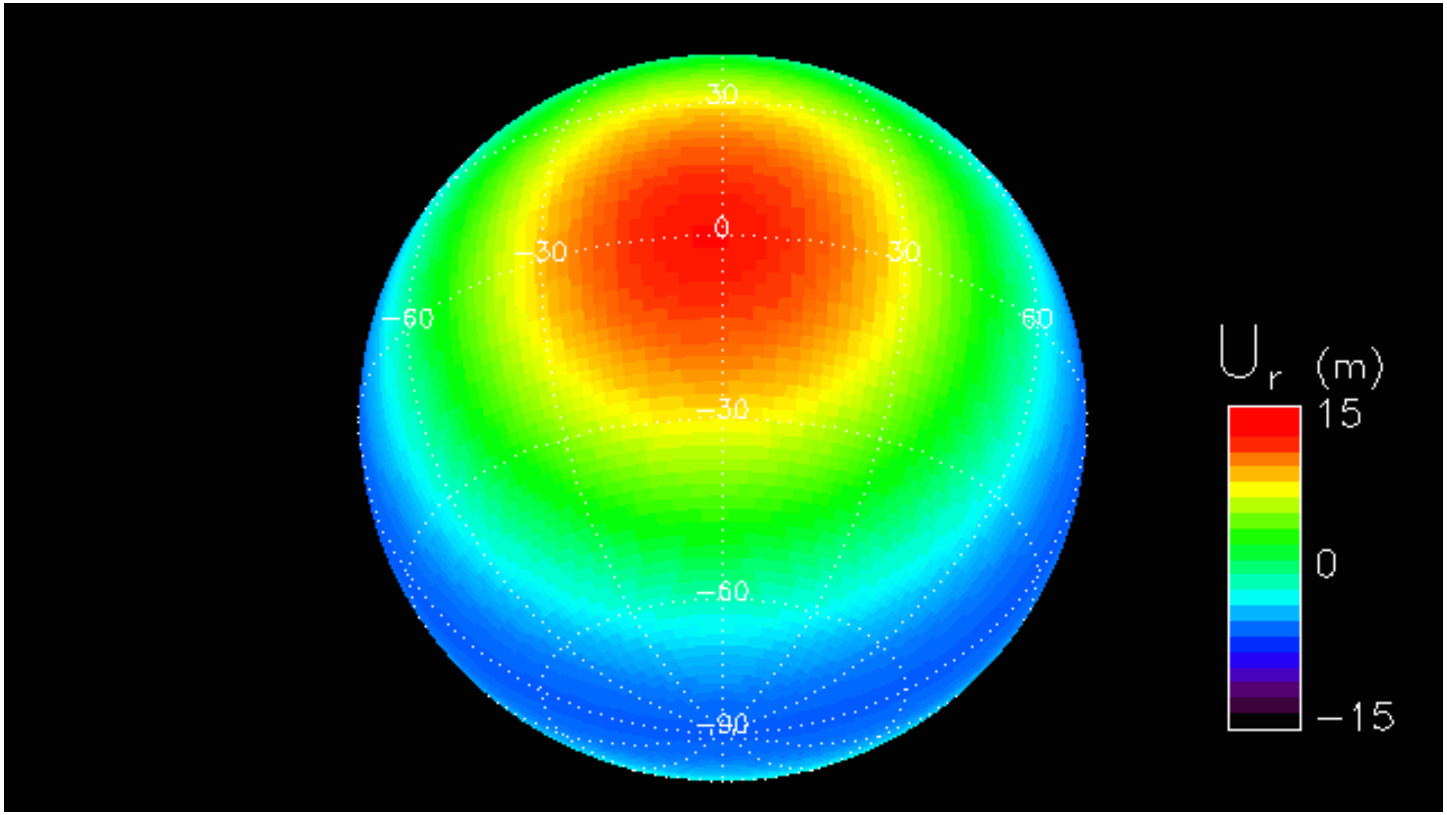
- **Titan is geologically very diverse and the composition of surface units is not fully identified**

- **Candidate landing sites are**
- Bright old terrain
- Plains of fluvial origin (Huygens)
- Cryovolcanic candidate areas and impact craters (subsurface access)
- Dunes (access to organics, climate history)
- Lakes (easy access to organics) and recent sedimentation activity (rivers and deposits)

- **Most targets of interest (lakes, rough terrain, erosional surface) need precise landing and mobility**
- This requires highly resolved surface information and robust landing technology
- Seems feasible as Huygens touched down on erosional surface

Annex

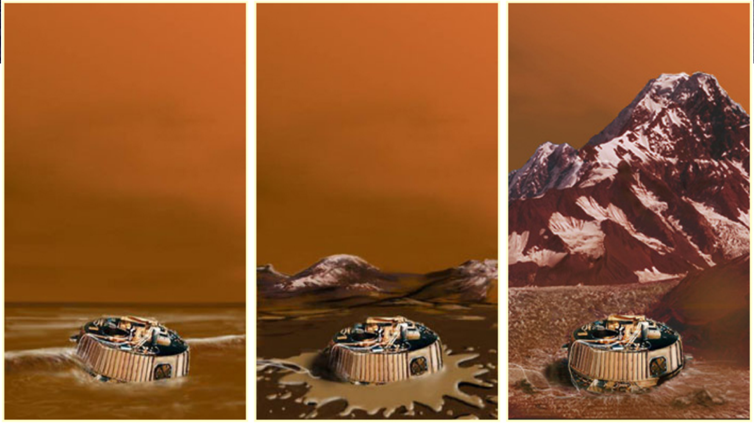
Radial Displacement



Credit: G. Tobie

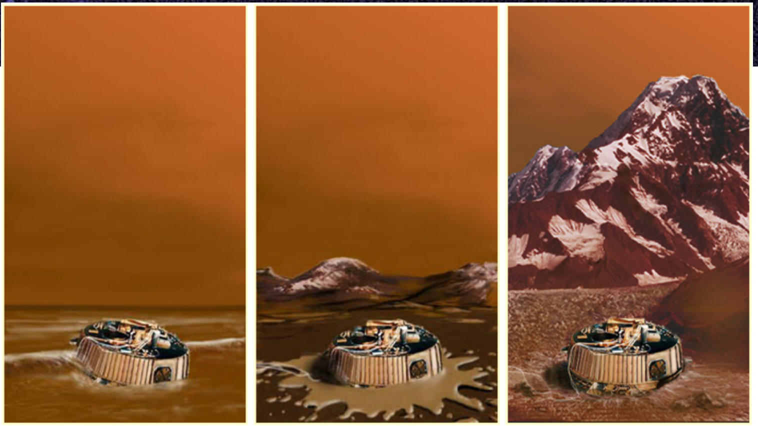
- Tidal cycle on Saturn-facing hemisphere of Titan

Engineering Constraints



- **Mission success:** Safety is of utmost importance and supersedes any other scientific or engineering constraint.
- **Terrain relief/slopes:** ‘free’ area over size of landing ellipse needed; avoid steep slopes, large pebbles, and rugged surface terrain.
- **Uniformity of surface features:** no changes between solid and liquid surface on smaller scales than the size of the landing ellipse.
- **Latitude and elevation:** Elevation plays an important role for the EDLS design.

Engineering Constraints



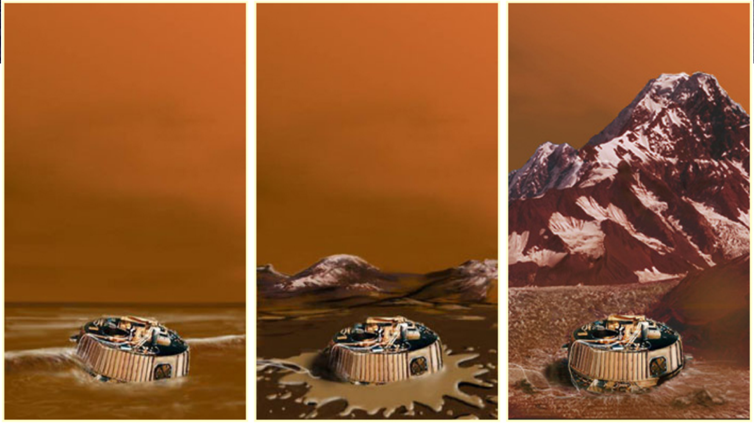
➢ **Landing ellipse/warning track:** Wind dispersion during parachute descent needs to be considered.

➢ **Atmospheric parameters:** Considering Titan's thick atmosphere, a system approach would favour a soft landing using parachutes rather than an active landing system.

➢ **Surface parameters at the landing site:** (i) be radar reflective to enable measuring altitude and velocity during descent, (ii) bear the load of the lander at landing, (iii) ambient temperatures within the lander design.

➢ **Illumination during late 2020s/early 2030s:** Strong in Southern summer and weak (scattered light & Saturn shine) in Northern winter. Maximum possible variations of illumination geometry occur at low altitudes.

Engineering Constraints

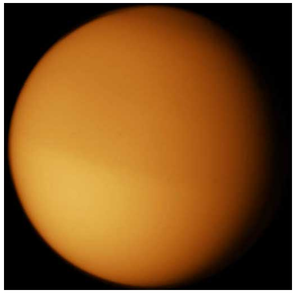


➢ **Power:** The low solar illumination on Titan's surface suggests the implementation of radioisotopic devices for electrical power generation.

➢ **Communication/tracking:** Low-latitude landing sites will 'see' Earth and Sun ~1/3 of the time – elevation changes continuously. High latitude (summer) landing site will see Earth and Sun 50-100% of the time, with rather constant (but low) elevation.

➢ **Delivery trade-off:** soft landings do not need to withstand high deceleration impacts, but are more restrictive in landing locations. Delivery accuracy will depend on entry angle. Allowable entry angles will depend on entry speed (from Titan orbit, Saturn orbit, or arrival hyperbola?)

Titan and Earth Comparison

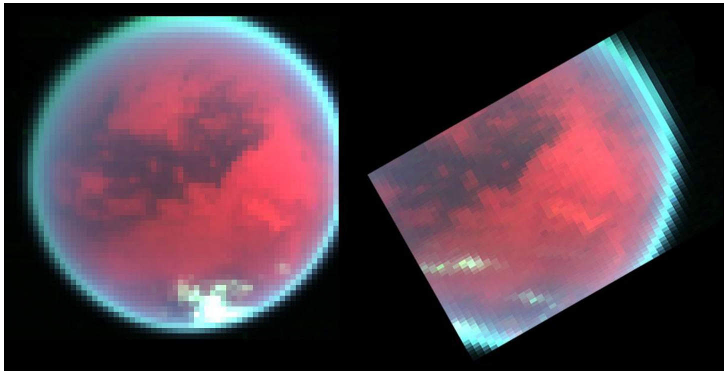


	Titan	Earth
Gravity	1/7	1
Pressure	1.5 bar	1 bar
Atmosphere	N2, CH4	N2, O2, CO2
Cloads & Rain	CH4, C2H6	H2O
Greenhouse	N2, CH4, H2	CO2, H2O
Temperature	-180 deg C	+ 15 deg C

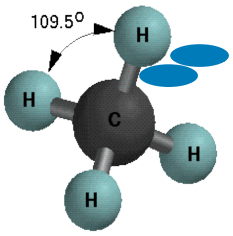
C. McKay, Titan ‘s Past, Present, and Future

Atmospheric Constituents

Major	
N2	95 - 99%
CH4	1 - 5%
H2	0.1%
Ar40	ppm



Credit: C. Griffith & VIMS team



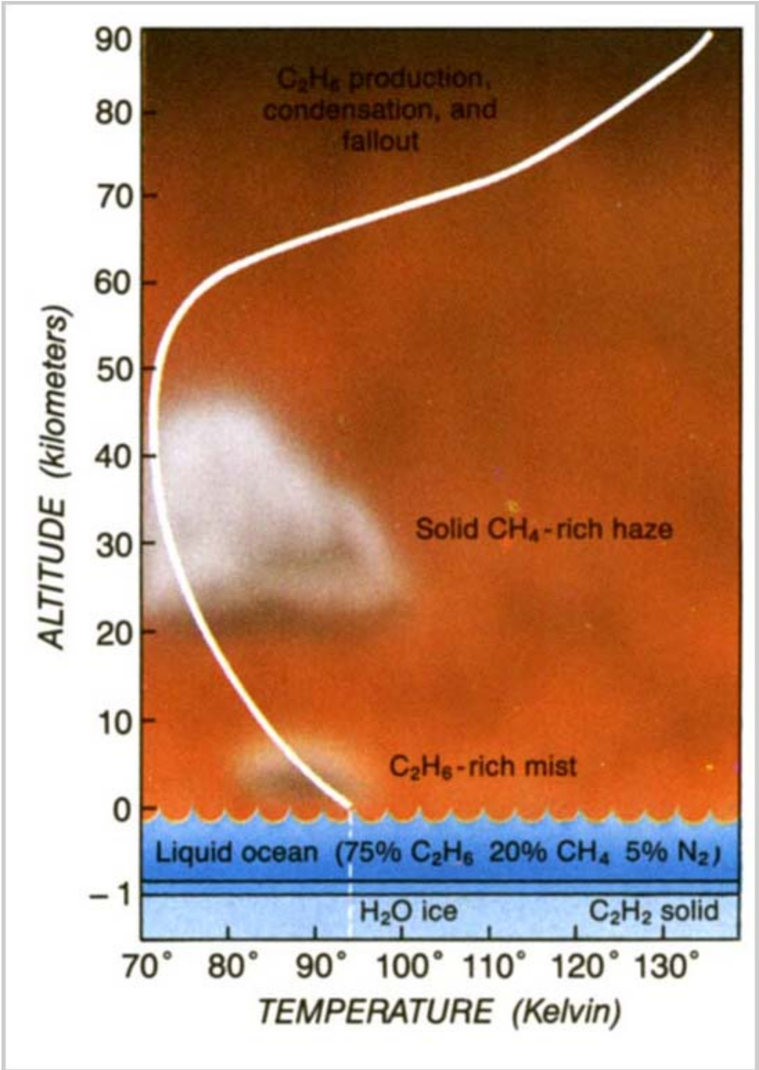
Minor	
C2H6	20 ppm
C3H8	5 - 20 ppm
C2H2	2 ppm
C2H4	400 ppb
C4H2	30 ppb
C6H6	0,4 ppb
…	…

- N2 and CH4 are strong greenhouse gases at Titan conditions
- Ar40 indicates rock-ice interaction at depth and subsequent release to atmosphere
- … but perhaps attributable to LHB (McKinnon 2010)

C. McKay, Titan ‘s Past, Present, and Future

Next Season of Titan (30 years)

- Equatorial temperature will not change more than +/- 1 K
- Pole temperatures will vary back-and-forth
- Locations of lakes will remain fixed
- … due to long radiative time constant (> 30 years)
- … low available flux for evaporation (cm/yr)
- **Poles are expected to stay dynamic and wet, equatorial regions to be calm and dry.**



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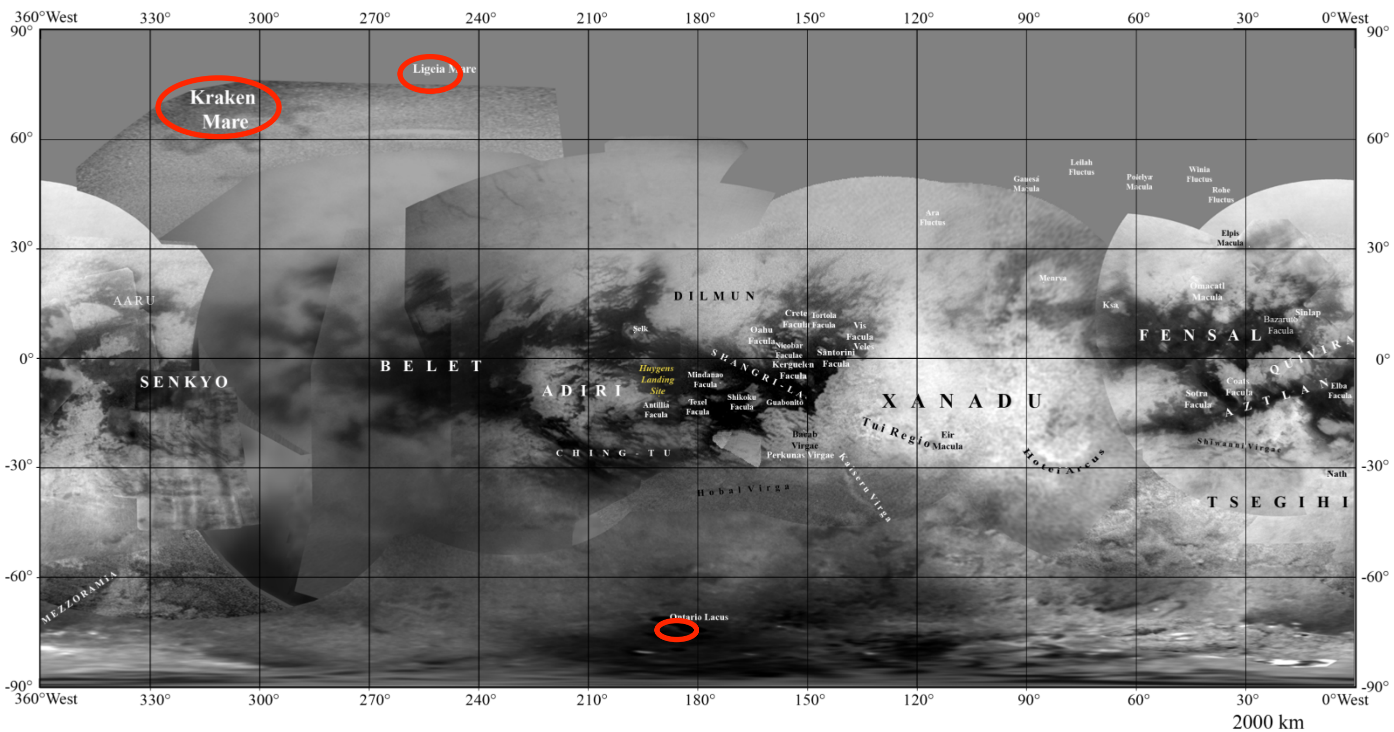
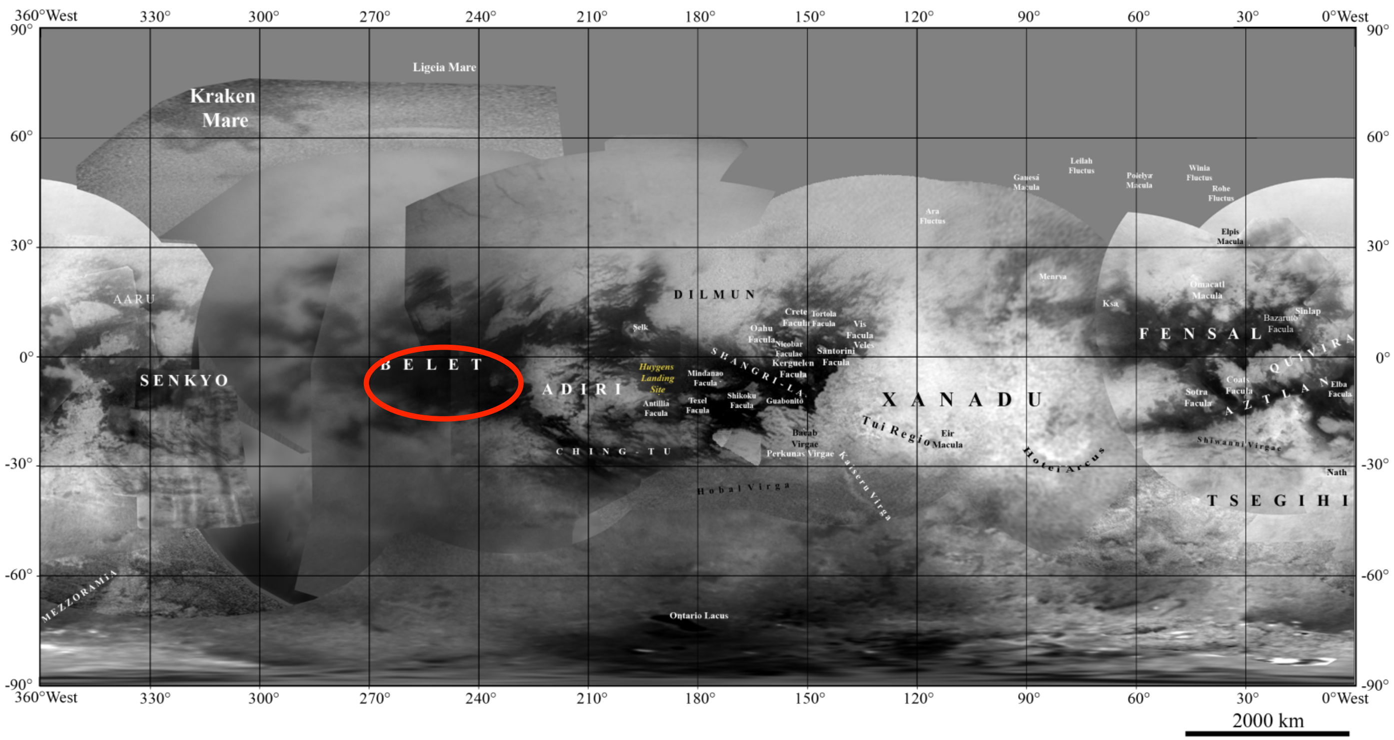
Polar Hydrocarbon Lakes



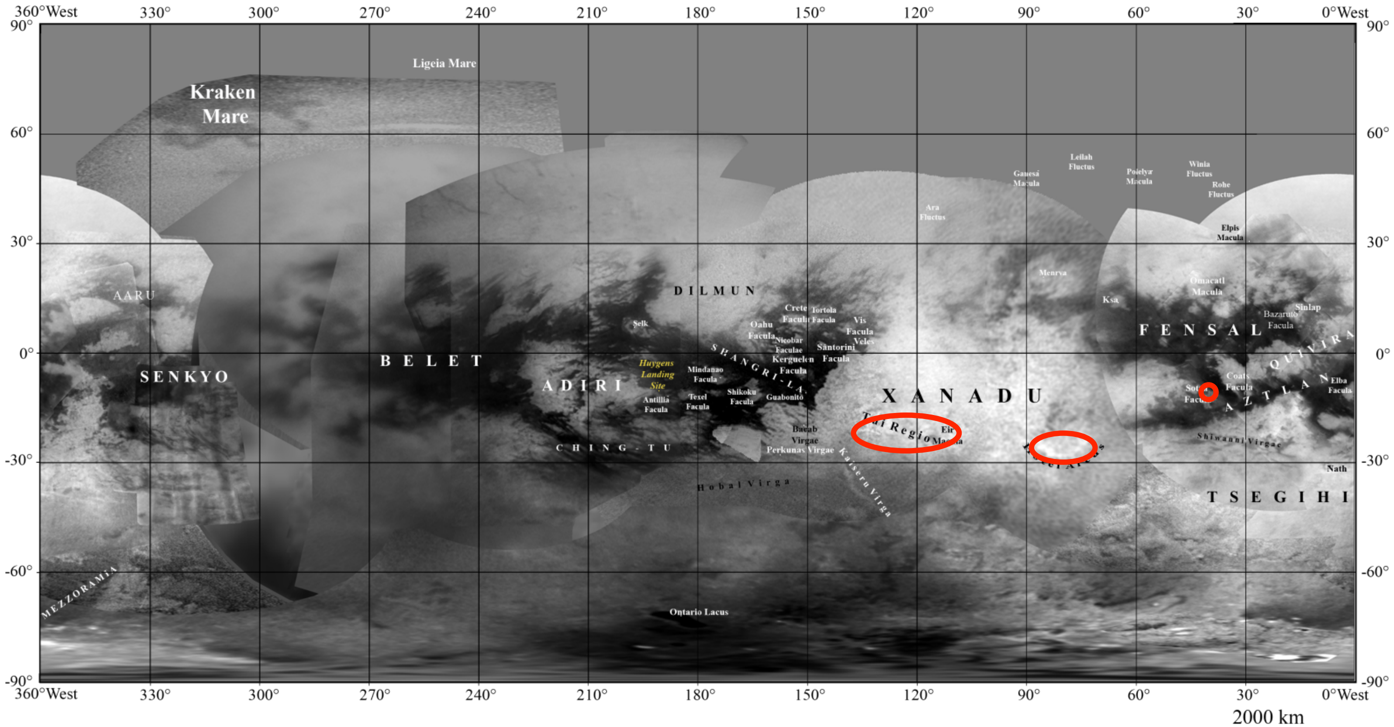
- Methane cycle and production of organic solids
- Precipitation of aerosols from above , release of noble gases from below

Equatorial Dune Fields

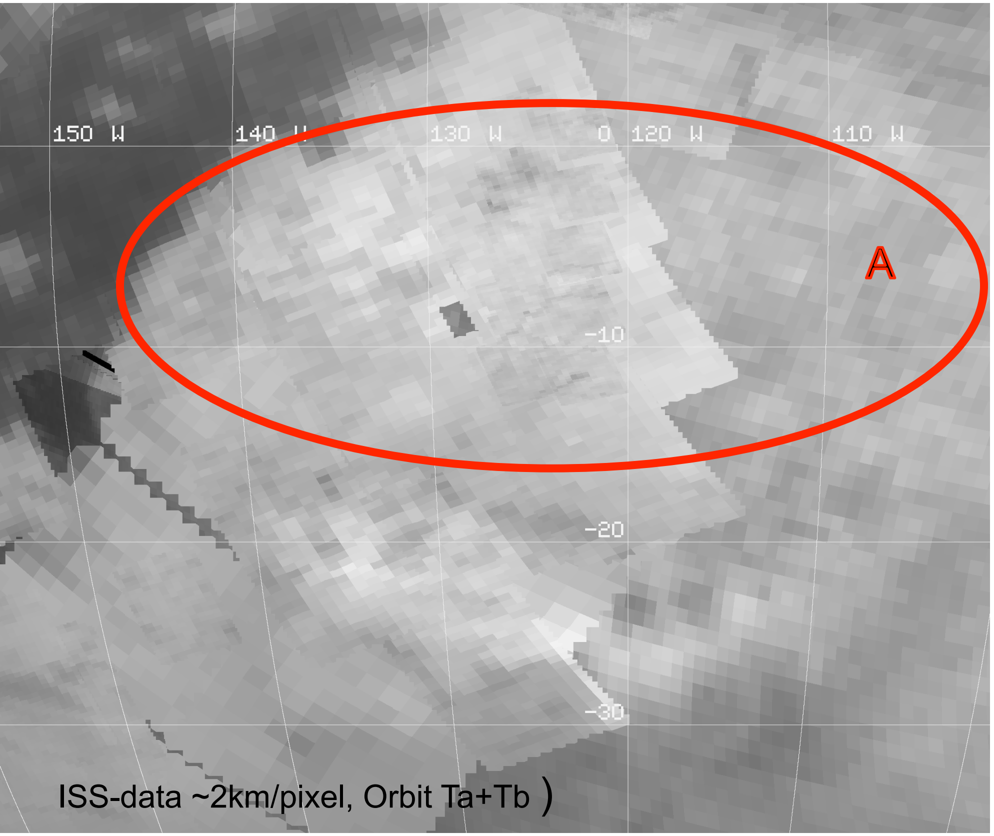


- Young aeolian surface features with high organic particle content
- Close relationship to recent erosional and depositional surface processes

Cryovolcanic candidate areas

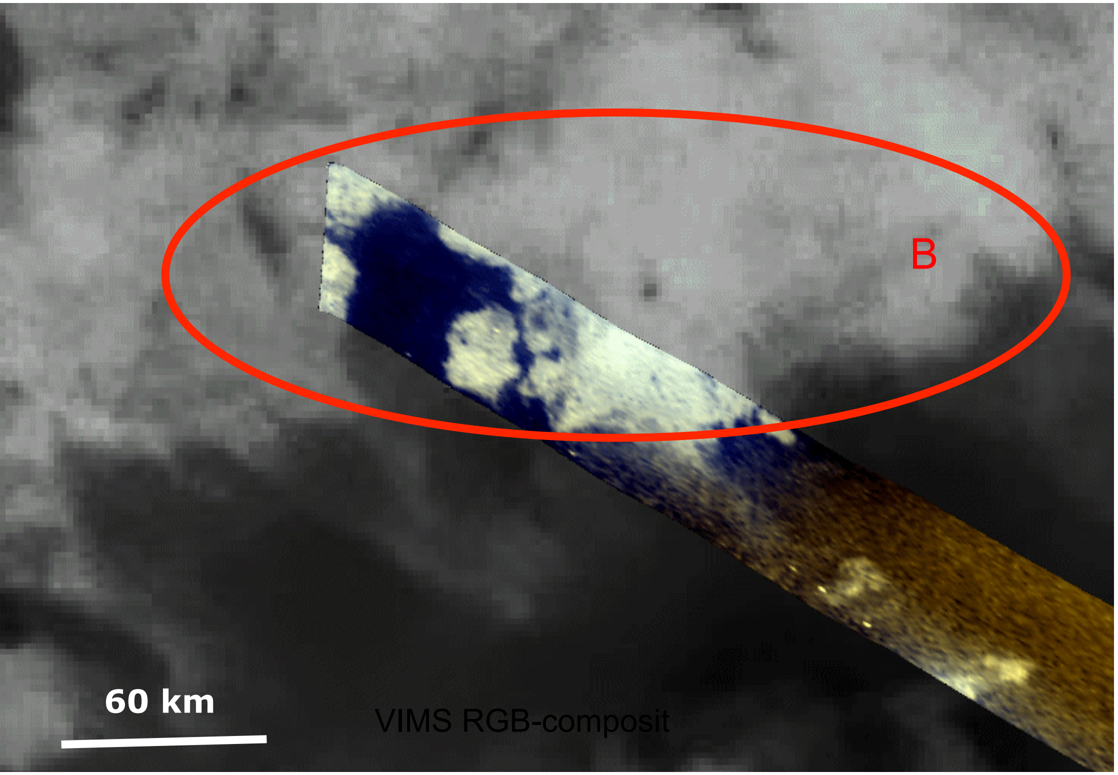


- Combined information on atmosphere, surface, shallow subsurface and deep interior

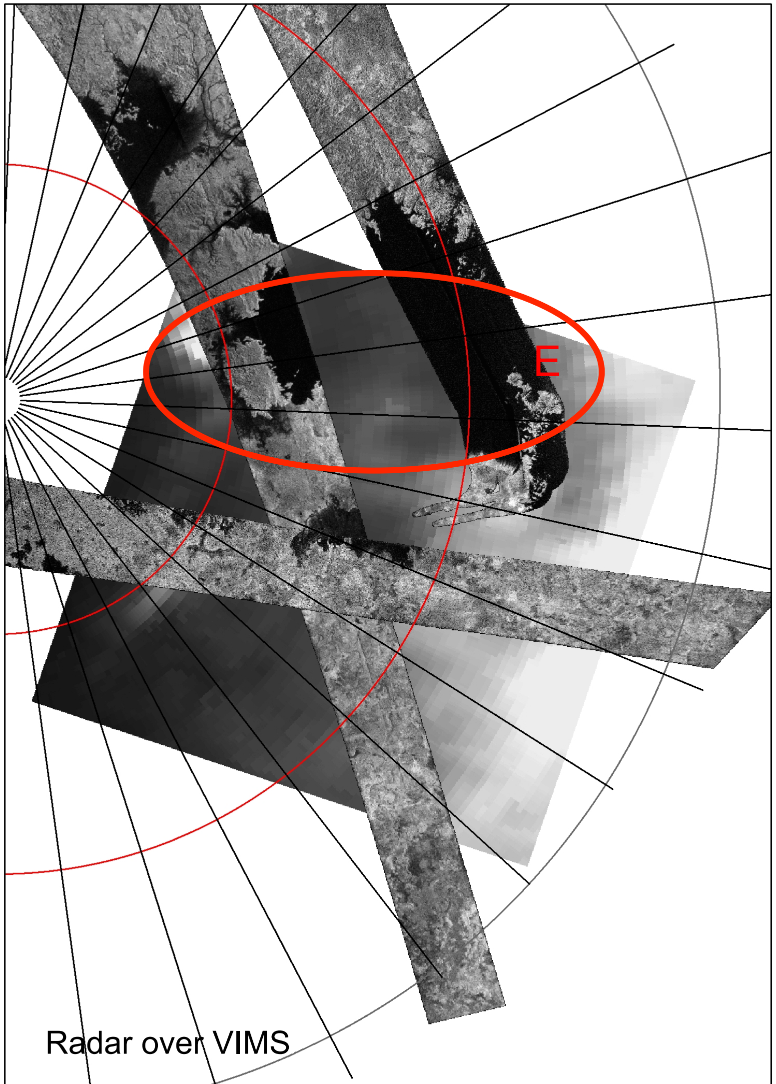


(A) Xanadu broadly defined as 'bright terrain' (can be hit by a 45x30 (2000x1300km) landing ellipse).
Coordinates: 110°W 12°S (center of ellipse)

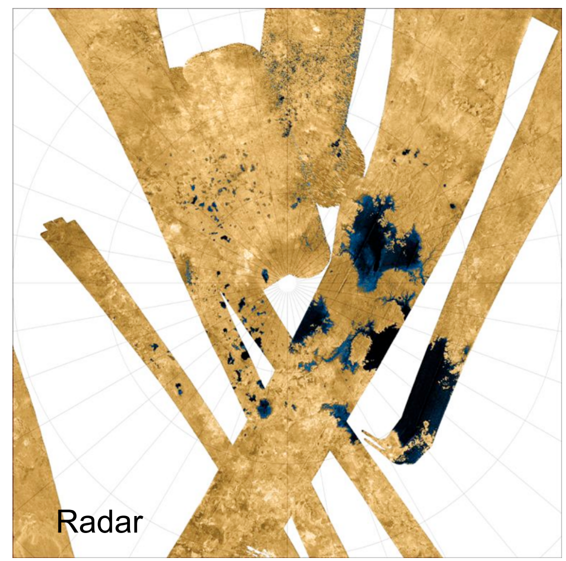
Complex albedo pattern in the western Xanadu may be due to tectonics.
The boundary between Xanadu and Shangri-la, a dark region to the west suggests that dark (spectraly bluish) material embays the bright terrain.
Radar images revealed dunes, hills, rivers and valleys present on Xanadu.



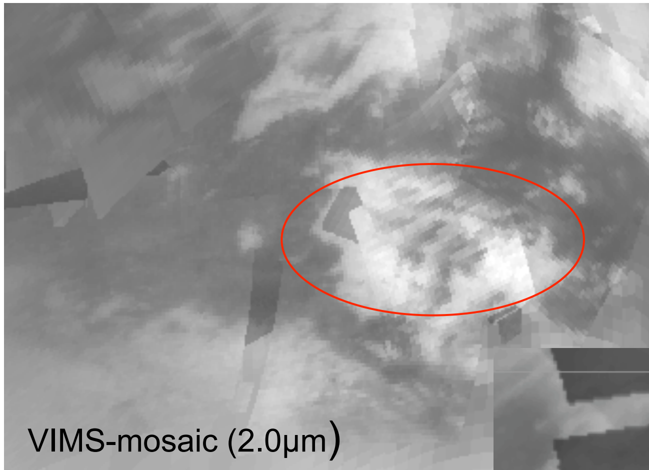
(B) Distinct blue alluvial units,
e.g **Chusuk Planitia** (landing ellipse of about 200x100km requires delivery accuracy of 100km or better?)
Coordinates: 30°W 7°S center of ellipse

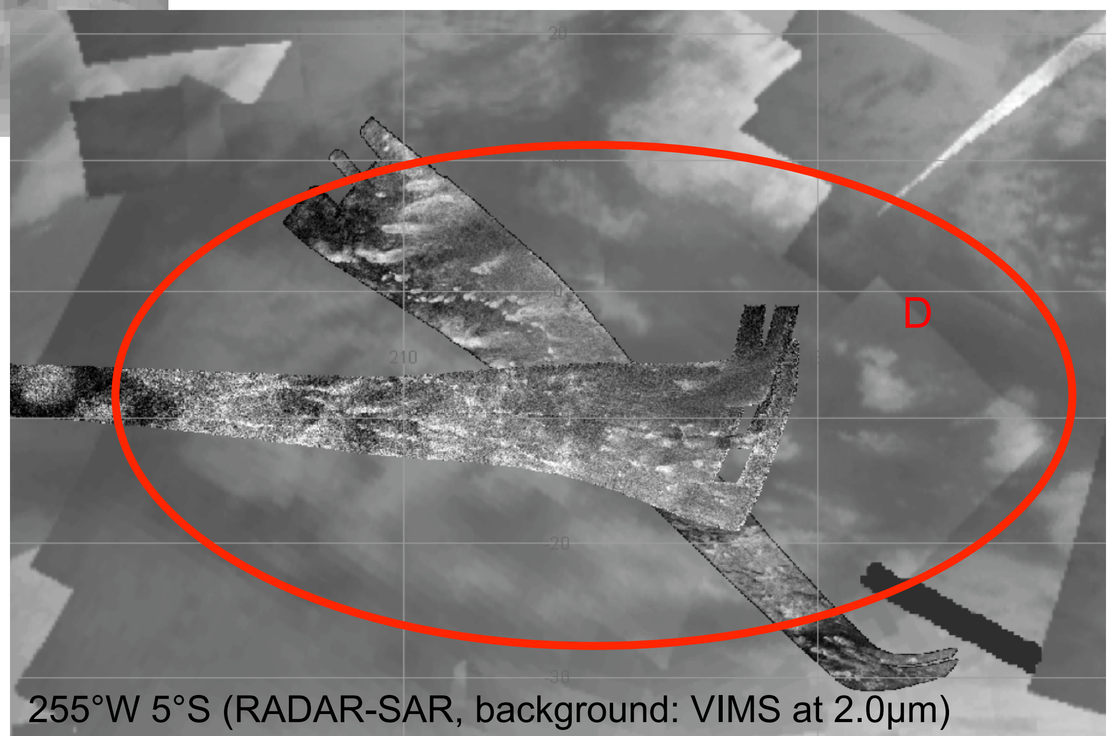


(E) **North Polar Lakes** above >72°N
(200km circular delivery error can be accommodated in Ligeia_Mare;
Kraken Mare can probably accommodate ~400km circular delivery zone)
coordinates: > 72°;

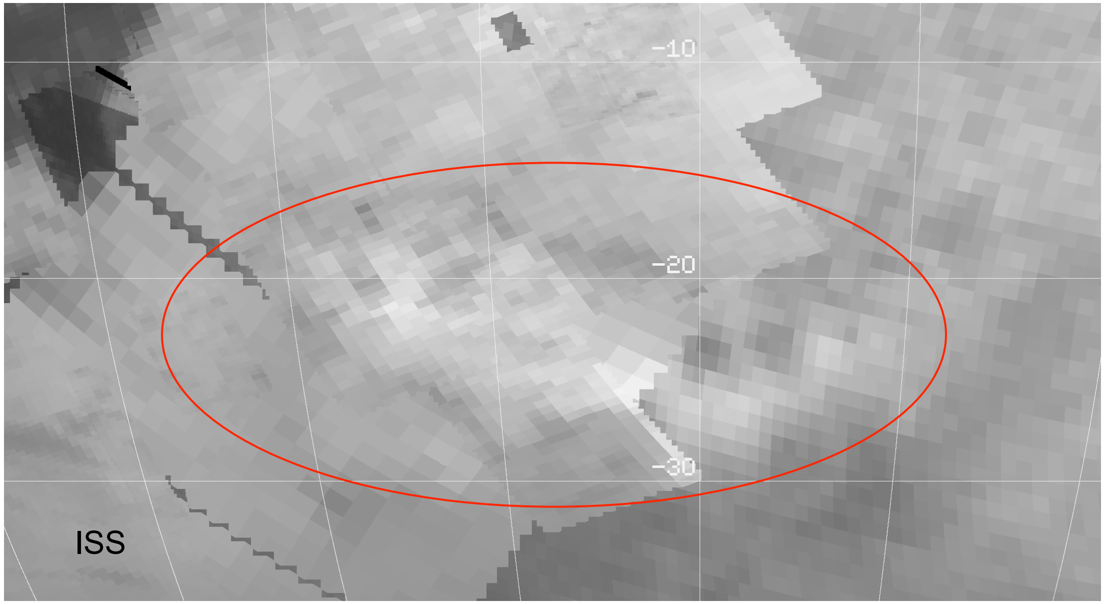


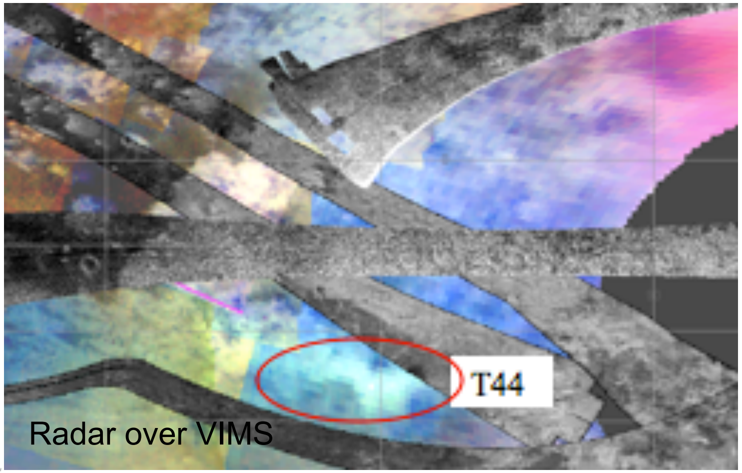
(D) Brownish dune units e.g. **Belet** dunefield (can be hit by a 15x40° (600x1600km) landing ellipse).
Coordinates: 255°W 5°S (center of ellipse);


VIMS-mosaic (2.0µm)



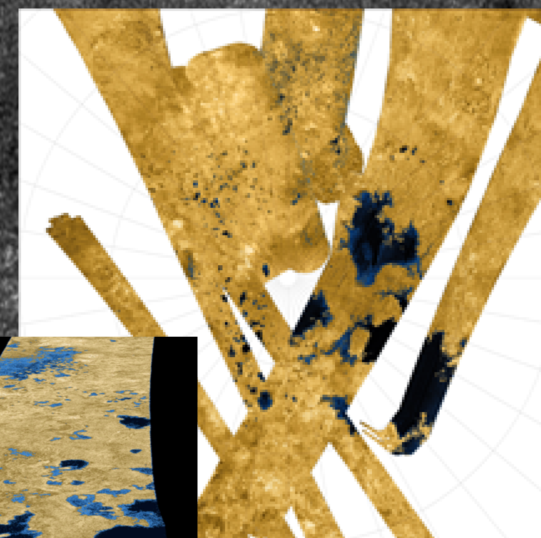
255°W 5°S (RADAR-SAR, background: VIMS at 2.0µm)



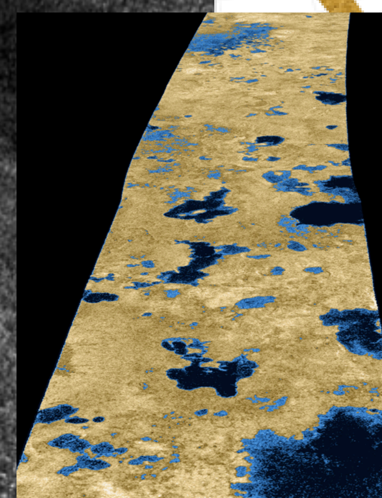


(F) Anomalous spectral region e.g. **Hotei/Tui Re**gio (~80% fit by 7x18° landing ellipse (300x800km) ~100% fit by 5x12° ellipse (200x500km)). Coordinates: 130°W 20°S (center of ellipse)

Lakes are exposed in polar regions > 70°;
with sizes < 10 km^2 to greater than 100,000 km^2 with circular to complex estuary/fjord-like shorelines and islands; either dry or filled with liquid) (e.g. Stofan et al. 2007, 2008; Brown et al., 2008)

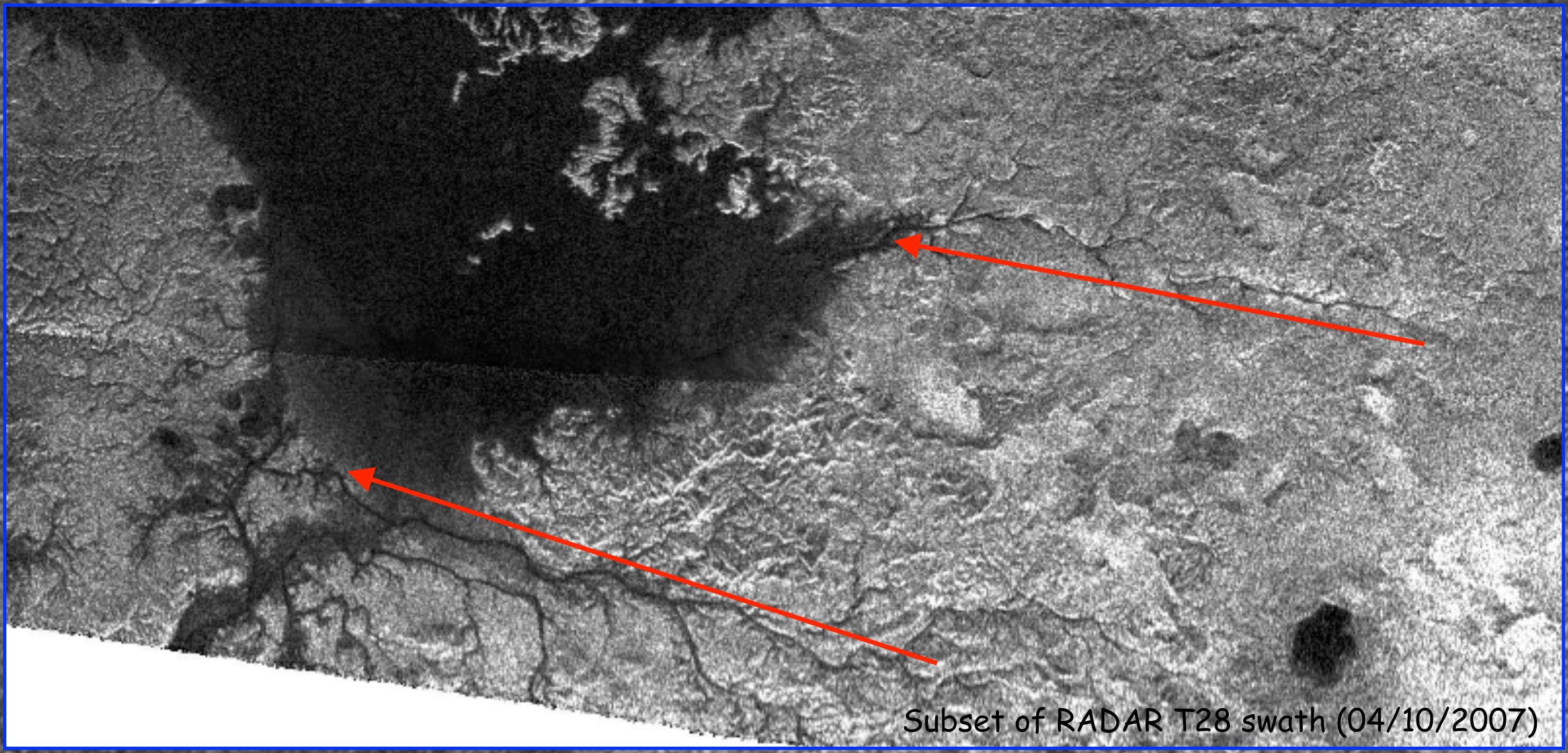


Lakes are either open systems or isolated indicating drainage or seepage processes and may originate from impact cratering, volcanism or karstic processes (e.g. Stofan et al. 2007, 2008)



Radar 22/22/07 T25

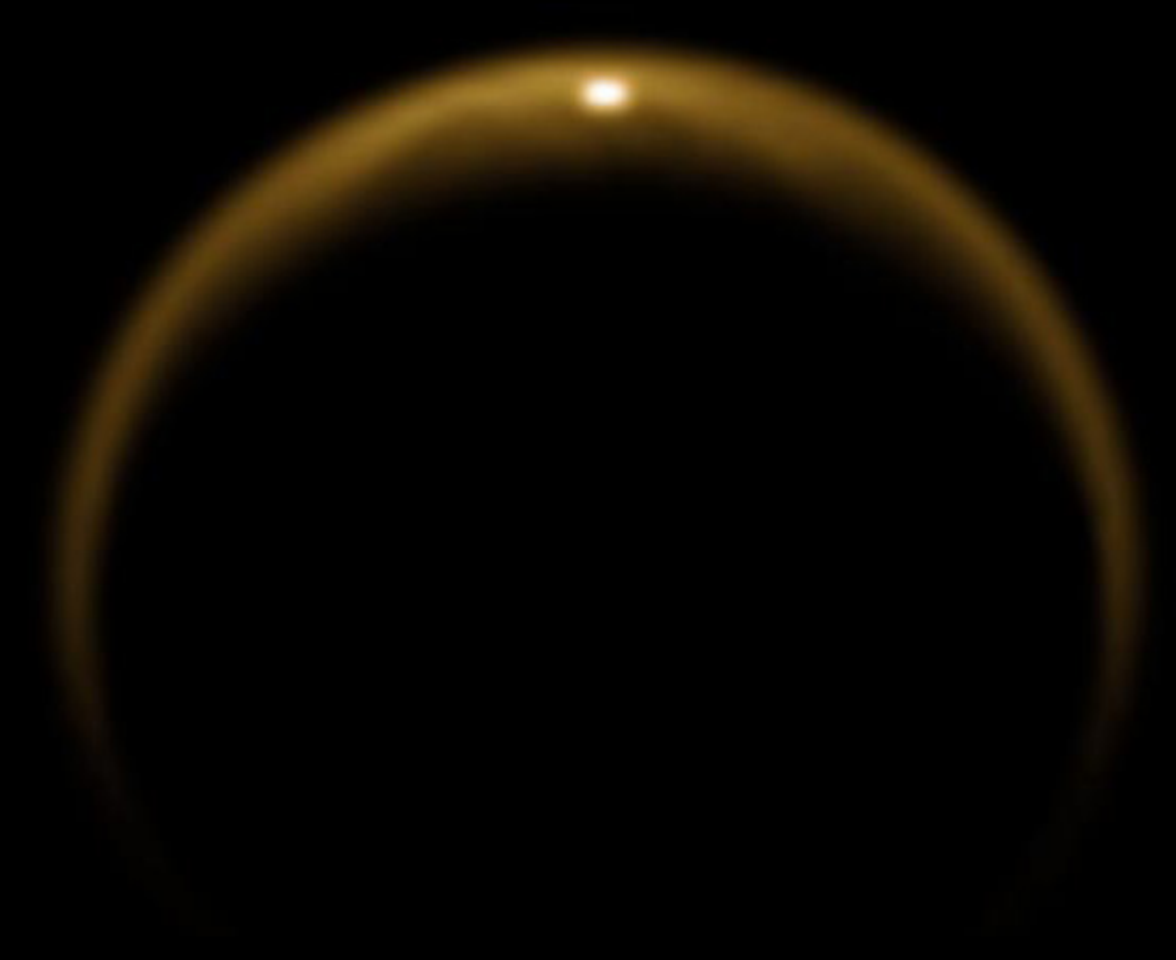
River systems: dendritic, meandering, branched networks; radar bright: suggesting to be filled with boulders radar dark: suggested to be filled with smooth deposits or liquid (e.g. Lorenz et al., 2006, Porco et al., 2005; Barnes et al., 2007; Lorenz et al., 2008;Jaumann et al., 2008,2009)

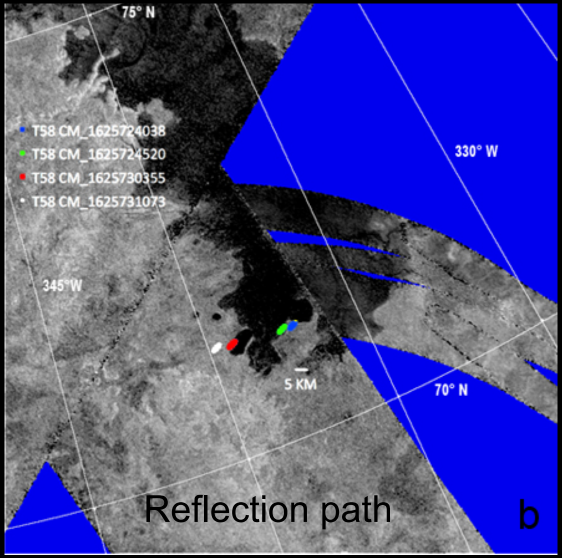


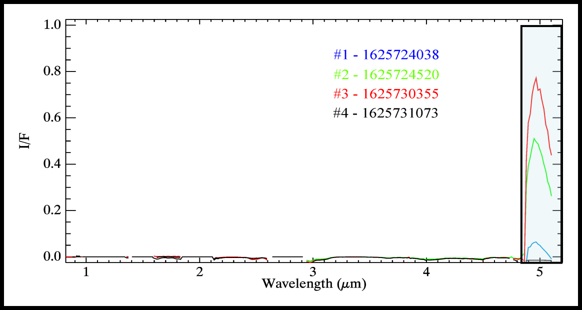
04/30/2006 Radar T13

30 km

Polar Hydrocarbon Lakes







➢ Strong, localized 5μm reflection in the northern polar region detected by Cassini VIMS (Stephan et al., 2010)

PIA 12481/ 8-Jul-2009